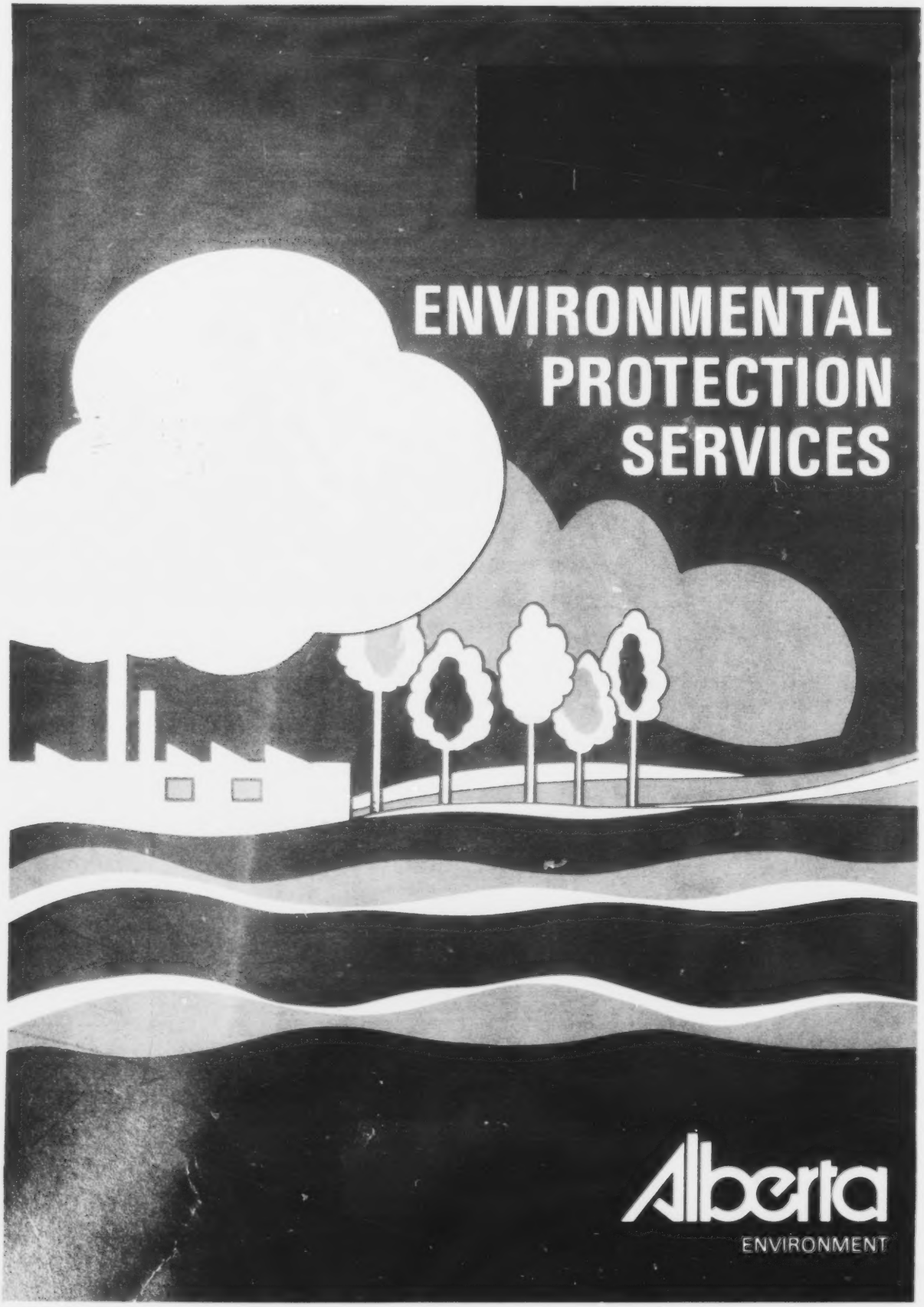
ENVIRONMENTAL
PROTECTION
SERVICES
Alberta
ENVIRONMENT

90-00215/

Alberta Department of the Environment
Library

RECLAMATION TRIALS ON SODIC MINE SPOIL AT BOW CITY, ALBERTA

by

S. FULLERTON (nee LANDSBURG)

H.F. REGIER

Earth Sciences Division
Soil Protection Branch

for

Alberta Environment
Environmental Protection Services

1987

ALBERTA ENVIRONMENT
050758

50758

#8705

EXECUTIVE SUMMARY

Since the passing of the Land Surface Conservation and Reclamation Act in Alberta in 1973, reclamation activities have been undertaken in areas mined and abandoned before 1963 when there were few regulations. Concerning these reclamation activities, there was a need for information to guide such undertakings, particularly concerning sodic spoil. As a result, reclamation trials were initiated in 1976 at an abandoned coal strip mine near Bow City, Alberta. The site is situated along the north bank of the Bow River approximately 40 km southwest of Brooks in the Eastern Alberta Plains. The area was mined for coal prior to 1963. At that time there were only provisions for continuous back-filling and contouring of areas stripped of overburden to obtain coal. As a result, mined land was left as a series of spoil piles: no topsoil was conserved and the overburden removed was windrowed in the order of extraction.

At Bow City the overburden contains a bedrock formation of late Cretaceous age. Known as the Bearpaw Formation, this saline, sodic bedrock is a fine-textured marine deposit containing bentonite. As a result of mining, the bedrock has been brought to the surface creating problems in revegetation. High amounts of sodium in the spoil causes clay dispersion, resulting in low water infiltration, and poor aeration and internal drainage. The combination of expanding clays and high concentrations of sodium produces material which is very hard when dry and a sticky mass when wet. The material is impermeable to water and roots, and is subject to erosion and extreme shrink-swell pressures.

The objectives of the reclamation trials were to: (1) assess the ability of various treatments in reducing the effects of high levels of sodium in the spoils, and (2) establish a permanent and useful vegetative cover on the spoil.

Two separate trials were set up as a split-plot experiment. Both trials were similar with the exception that only one was irrigated. Each trial consisted of three replicates, of seven treatments. The seven treatments tested included: (1) control; (2) cow manure applied at 50 dry t ha^{-1} and incorporated to a depth of 10 cm; (3) sewage sludge applied at 38 dry t ha^{-1} and incorporated to a depth of 10 cm; (4) calcium

chloride ($CaCl_2$) applied at 6600 kg ha^{-1} and incorporated to 10 cm; (5) gypsum ($CaSO_4$) applied at 6600 kg ha^{-1} and incorporated to 10 cm; (6) topsoil applied to the surface to a depth of 15 cm; and (7) spoil embankments built to a height of 35 cm.

One half of each plot was fertilized with nitrogen and phosphorus in 1976 and 19[illegible]. After plot establishment in the fall of 1976, all plots were irrigated once in an attempt to promote fall forage establishment. After the fall of 1976, the irrigated plots were periodically irrigated over a four year period. The plots were seeded to a forage mixture in 1976 and again in 1977 because of poor crop growth from the 1976 seeding.

Three soil samples per plot were taken in 15 cm increments from 0 to 60 cm in 1978, 1981, and 1984. Each sample was analyzed for pH, electrical conductivity (EC), saturation percentage (sat.%), calcium (Ca), magnesium (Mg), sodium (Na), and chloride (Cl). Two vegetation samples per plot were taken for yield measurements in 1980, 1981 and 1983.

Fertilizer had no effect on plant growth or any of the soil variables measured. The sewage sludge, manure, and soil embankment treatments were also ineffective in amending sodic spoil or promoting vegetative growth.

Topsoil was the most effective irrigated and non-irrigated treatment in terms of reducing the high levels of Na and establishing a permanent useful vegetative cover. It provided a non-contaminated root zone which allowed vegetation to establish immediately, and promoted some leaching over the long-term. The upward movement of salts from sodic spoil into topsoil was noted, and may be a problem under non-irrigated conditions.

$CaCl_2$ was the second most effective irrigated and non-irrigated treatment. $CaCl_2$ was the best treatment in terms of promoting leaching and therefore the downward movement of salts. Leaching was maximized at

30 cm under non-irrigated conditions and 60 cm under irrigated conditions. The irrigated treatment had yields which were significantly higher than the control treatment, while the non-irrigated treatment did not.

Both gypsum treatments were ineffective in reclaiming sodic spoil as they promoted the upward movement of salt. This may have been due to the low solubility of gypsum.

Yields were much lower than adjacent undisturbed areas regardless of the type of reclamation treatment applied.

In general, results of these reclamation trials indicate that when mining for coal in areas containing sodic bedrock the best method to be used to ensure reclamation seems to be to conserve suitable materials for soil reconstruction. These trials could be conducted under other environmental conditions besides semi-arid to see if the same treatment results would occur.

TABLE OF CONTENTS

		Page
LIST OF TABLES		vii
LIST OF FIGURES		ix
ABSTRACT		x
ACKNOWLEDGEMENTS		xi
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	1
2.1	Sodic Spoil	1
2.2	Reclamation of Sodic Spoil	2
2.2.1	Physical Amendments	3
2.2.2	Chemical Amendments	5
3.	STUDY AREA	7
3.1	Location	7
3.2	Climate	7
3.3	Vegetation	7
3.4	Geology	7
3.5	Soils	9
4.	MATERIALS AND METHODS	9
4.1	Experimental Design	9
4.2	Seeding, Fertilization, Irrigation and Weed Control	11
4.3	Soil Sampling and Analyses	12
4.4	Plant Sampling	12
4.5	Statistical Analyses	12
5.	RESULTS	13
5.1	Topsoil Treatment	13
5.1.1	Non-Irrigated	13
5.1.2	Irrigated	16
5.2	$CaCl_2$ Treatment	17
5.2.1	Non-Irrigated	17
5.2.2	Irrigated	19
5.3	Gypsum Treatment	20
5.3.1	Non-Irrigated	20
5.3.2	Irrigated	20
6.	DISCUSSION	23
6.1	Non-Irrigated Trials	23
6.2	Irrigated Trials	24
6.3	Yield	26
7.	CONCLUSIONS	28

TABLE OF CONTENTS (CONCLUDED)

		Page
8.	REFERENCES CITED	29
9.	APPENDICES	32
9.1	Treatment Analyses	32
9.2	Soil Analytical Methods	32
9.3	Soil Data: 1978 to 1984	32
9.4	Plant Data: 1980 to 1983	32
9.5	Results of Statistical Analyses	32

LIST OF TABLES

		Page
1.	Significant effects of treatment, depth and year on sat%, pH, EC, Ca, Mg, Na, SAR, Cl and yield	14
2.	Trends with depth over time for the topsoil treatment	15
3.	Trends with depth over time for the $CaCl_2$ treatment	18
4.	Trends with depth over time for the gypsum treatment	21
5.	Comparison of mean plot yields to local yields for the years 1980, 1981 and 1983	27
*6.	Characteristics of sodic spoil at Bow City before treatment ..	33
*7.	Characteristics of topsoil used at Bow City	34
*8.	Characteristics of the cow manure, sewage sludge and gypsum used at Bow City	35
*9.	Characteristics of the irrigation water used at Bow City	36
*10.	Soil analytical methods	37
*11.	Means of analyses performed on non-irrigated samples: 1978....	38
*12.	Means of analyses performed on non-irrigated samples: 1981....	40
*13.	Means of analyses performed on non-irrigated samples: 1984....	42
*14.	Means of analyses performed on irrigated samples: 1978.....	44
*15.	Means of analyses performed on irrigated samples: 1981.....	46
*16.	Means of analyses performed on irrigated samples: 1984.....	48
*17.	Mean yields for non-irrigated plots	50
*18.	Mean yields for irrigated plots	51
*19.	Effect of treatment and the year x treatment interaction on sat.% at the 0 to 15 cm depth	52
*20.	Effect of treatment and the year x treatment interaction on pH at the 0 to 15 cm depth	53
*21.	Effect of treatment and the year x treatment interaction on EC	54

LIST OF TABLES (CONCLUDED)

Page

*22. Effect of treatment and the year x treatment interaction on concentrations of Ca at the 0 to 15 cm depth 55

*23. Effect of treatment and the year x treatment interaction on concentrations of Mg at the 0 to 15 cm depth 56

*24. Effect of treatment and the year x treatment interaction on concentrations of Na 57

*25. Effect of treatment and the year x treatment interaction on SAR at the 0 to 15 cm depth 58

*26. Effect of treatment and the year x treatment interaction on concentrations of Cl 59

*27. Interaction of treatment with year for sat.%, pH, EC, Ca, Mg, Na, SAR and Cl 60

*28. Test for trends for depth at the non-irrigated plots in 1978 62

*29. Test for trends for depth at the non-irrigated plots in 1981 64

*30. Test for trends for depth at the non-irrigated plots in 1984 65

*31. Test for trends for depth at the irrigated plots in 1978 66

*32. Test for trends for depth at the irrigated plots in 1981 67

*33. Test for trends for depth at the irrigated plots in 1984 68

*34. Interaction of year x treatment for the yield data 69

* Tables 6 to 34 are in the appendices section.

LIST OF FIGURES

Page

1. Location of the Bow City reclamation plots 8

2. Experimental design of the Bow City reclamation plots 10

ABSTRACT

The purpose of this project was to test seven treatments for the reclamation of sodic spoil. The sodic spoil was located at an abandoned coal mine in South-Eastern Alberta. The objectives of the study were to: (1) assess the ability of various treatments in reducing the effects of high levels of sodium in the spoil, and (2) establish a permanent and useful vegetative cover.

Two similar sets of plots were set up as a split-plot experiment, and only one set was irrigated. The treatments consisted of topsoil, calcium chloride ($CaCl_2$), gypsum, cow manure, sewage sludge, soil embankments and a control of sodic spoil.

Over a period of eight years, each plot was sampled 3 times in 15 cm increments from 0 to 60 cm. Two yield samples per plot were also collected. Soil analyses monitored consisted of pH, electrical conductivity, saturation percentage, and water-soluble calcium, magnesium, sodium, and chloride.

Results showed topsoil followed by $CaCl_2$ to be the best irrigated and non-irrigated treatments. Topsoil provided an immediate uncontaminated root zone where vegetation could establish, and $CaCl_2$ provided leaching of excess sodium through replacement by calcium and increased flocculation. The use of fertilizer and the remaining treatments had no significant effects on any of the plant or soil variables monitored.

In general, the results of the trial indicated that where sodic material is present during surface mining, adequate non-contaminated materials should be saved for soil reconstruction after mining.

ACKNOWLEDGEMENTS

Thanks are extended to Mr. F. Kacsinko for his field work, and the laboratory staff of the Soil Protection Branch, Earth Sciences Division, for laboratory activities. Appreciation is expressed to Mr. P Minarik for thoroughness in statistical evaluations. The typing expertise provided by Mrs. Kearl and Mrs. B. Lundstad was invaluable in the preparation of this manuscript.

1. INTRODUCTION

Since the passing of the Land Surface Conservation and Reclamation Act in Alberta in 1973, reclamation activities have been undertaken in areas mined and abandoned before 1963 when there were few reclamation regulations. One area requiring information regarding reclamation was that of sodic mine spoil. Hence, reclamation trials were initiated in 1976 at an abandoned coal strip mine near Bow City, Alberta.

At Bow City the overburden contains bedrock from the Bearpaw Formation, a fine-textured sodic and saline marine deposit containing bentonite. As a result of mining, the bedrock was brought to the surface creating problems in revegetation. Large amounts of sodium in the spoil causes clay dispersion, resulting in low water infiltration, and poor aeration and drainage. The combination of bentonite and high concentrations of sodium produces material which is very hard when dry and a sticky mass when wet. The material is impermeable to water and roots, and is subject to erosion and extreme shrink-swell pressures.

The objectives of the reclamation trials were to: (1) assess the ability of various treatments in reducing the effects of high levels of sodium in the spoil, and (2) establish a permanent and useful vegetative cover.

2. LITERATURE REVIEW

2.1 SODIC SPOIL

The term sodic is applied to a soil containing sufficient sodium to interfere with the growth of most crop plants, and having an exchangeable sodium percentage (ESP) of 15 or more (Canada Department of Agriculture 1976). Other common characteristics associated with sodic material include an electrical conductivity (EC) less than 4 dS m^{-1} at 25^{o}C, and a pH between 8.5 and 10 (Richards 1954).

Sodic material is a dispersed soil system where soil particles tend to repel one another, permitting each particle to act independently cf the other. As a result, poor physical soil conditions are created.

Dispersed soils are muddy, plastic-like and sticky when wet, and hard and impermeable when dry. Such soils have low hydraulic conductivities and severely reduced infiltration, particularly if a surface crust forms. The soil is extremely difficult to break into aggregates, and when dry is impervious to water and air movement, and root growth.

The severity of all the problems associated with sodic materials is increased by the presence of large amounts of montmorillonite clay. Not only is sodium adsorption enhanced but the effect of swelling and subsequent dispersion of clay units is magnified.

Serious soil erosion can occur in soils with such unfavorable structure. Low infiltration and hydraulic conductivity may cause surface ponding resulting in the loss of large quantities of soil and water through runoff. Piping erosion is a common occurrence on sodic mine spoil and is thought to develop as a result of deep surface cracks providing a pathway through which water can move (Gee et al. 1978).

In general, the high sodium clays or sodic spoil materials present numerous problems such as: (1) impermeability to water, making the exchange and leaching of sodium nearly impossible; (2) high soluble salt content concentrated near the soil surface, therefore prohibiting germination of many species and restricting all but the most salt tolerant seedlings; and (3) crusting on the soil surface inhibiting seedling emergence, and inducing surface runoff, and accelerated erosion (Brocke 1976).

2.2 RECLAMATION OF SODIC SPOIL

There are a number of ways to approach the reclamation of sodic spoil. Improving soil structure and thereby increasing water permeability and root penetration may be accomplished by various chemical and physical methods. Increasing the amount of soil water for salt leaching and improving drainage may also permit reclamation of unfavorable sodic material. Cropping and management practices that reduce evaporation and try to reduce excessive salts may also be applied to mine reclamation in its later stages (Fyles 1982). Only those reclamation techniques used in this research project will be reviewed.

2.2.1 Physical Amendments.

The addition of organic matter (manure, sewage sludge, straw, etc.) to sodic soil improves the structure and promotes water movement. Organic matter interacts with the inorganic material and tends to reduce swelling and dispersion of clay. It may also serve as an energy source for microorganisms which in turn can promote stable aggregation of soil particles (Bower et al. 1951). The beneficial effects of organic matter were noted by Harron (1979) in his work on sodic soils. He observed that for similar sodium adsorption ratio (SAR) values, the hydraulic conductivities in A horizon samples were considerably higher than in B horizon samples. He attributed these results to the lower organic matter content and higher clay content in the subsoil.

If plants can be established on sodic materials, they improve the soil tilth through growth and decomposition. Roots add organic materials to the soil thus enhancing soil structure, and opening channels which permit percolation of water into the soil. By removing water throughout the rooting zone, they reduce the upward movement of salts. Some deep rooted plants may even lower the water table (White and de Jong 1975). Plants may also reduce evaporation from the soil surface though shading (Luken 1962).

Topsoiling is the most commonly used method of reclamation of sodic mine spoil. Legislation in the United States requires that original soil material be removed and stockpiled before mining, and replaced on mine spoils after reshaping (Power et al. 1978). Current guidelines for agricultural areas in Alberta recommend the replacement of 300 cm of soil material if it is available (Alberta Agriculture 1981). Both depth and specific chemical and physical properties are used to determine the suitability of soil material for replacement.

The success of reclamation methods which involve soil replacement has been studied in the northwestern United States with varied results. In 1970, when the reclamation of mine spoil using topsoil was first studied, the effect of two inches of topsoil placed on sodic spoil was monitored over a six year period (ARS and NDSU Staff 1977). Results included good to excellent stands of western wheatgrass

and green needlegrass on the topsoiled plots, and very sparse vegetative growth on areas where no topsoil had been applied. Further work examining the effect of varying topsoil thickness and quality on yield of crested wheatgrass at four mine sites was started in 1973 and 1974 (SEA and NDSU Staff 1979). Results indicated that crop productivity was reduced by low quality underlying spoil materials. There was a progressive increase in the SAR of the surface applied 30 cm of topsoil during the four year period. The SAR of the 15 to 30 cm depth of topsoil increased more than ten times, while that of the surface 15 cm of soil was unaffected by sodium migration (Fyles 1982).

A more recent study by Power et al. (1981) involved a wedge of subsoil ranging in thickness from 0 to 210 cm on top of sodic mine spoil. In general, crop yield increased as total soil thickness increased to 90 cm, and in most plots, over 90% of the maximum yields were obtained when 70 cm subsoil plus 20 cm topsoil covered the sodic material. The results suggest that a minimum of 90 cm of soil material is required over sodic spoil to obtain maximum production of most crops. Further experiments supported the use of at least 120 cm of replaced soil when available, due to possible losses by erosion (Fyles 1982).

In contrast to the above experiments, Dollhoph and DePuit (1981) found mine spoil physics to govern whether in fact topsoil sodification would occur. Soil physical characteristics such as texture, clay mineralogy, and the rate of mine spoil water movement governed whether a mine site would experience sodium migration into topsoil.

The determination of thickness requirements for materials placed over sodic spoil must make allowances for the upward migration of sodium from spoil into topsoil, the physical characteristics of the spoil, settling and subsidence, surface erosion, and uneven spreading of soil.

Numerous field trials have demonstrated the effectiveness of leaching through irrigation as being an effective way to remove excess salts and exchangeable sodium from the plant root zone. Reeve et al. (1984) found that gypsiferrous, saline-sodic soils were reclaimed by leaching with 1.2 m of water. Heald et al. (1950) found leaching to

promote the germination of sugar beets and increase yields in saline conditions. Spoil materials which are fine textured and sodic will have slow water infiltration rates and high water holding capacities. Consequently, the moisture that enters the spoil material will usually be retained in the upper few centimeters and will be lost by evaporation. Leaching will progress at a very slow rate, especially in arid areas. In areas of higher precipitation, sodic spoil may eventually be reclaimed (Sandoval and Gould 1978).

2.2.2 Chemical Amendments

Reclamation of sodic spoil involves the replacement of a certain portion of the sodium on the exchange complex with divalent cations. One group of possible amendments is calcium sources such as gypsum and calcium chloride.

Gypsum ($CaSO_4.2H_2O$) is the most commonly used chemical in the reclamation of soils adversely affected by sodium. The usefulness of gypsum is limited by its low solubility in water, particularly if the EC of the soil is greater than 2 dS m^{-1} and sulphate ions are predominant (Regier 1986 personal communication). As well, solubility decreases at pH values greater than 9 (White and de Jong 1975). Therefore, large quantities of water must be added to spoil amended with this chemical to affect complete dissolution. Since the hydraulic conductivity of sodic materials is often very low, this also implies a considerable time requirement for reclamation (Hadas 1973).

Without physical incorporation the effectiveness of gypsum may be restricted to the top few centimeters of the soil due to low hydraulic conductivity of the subsurface layer. Even after incorporation, a sudden rain may cause crust formation if insufficient time has elapsed for solubilization (Fyles 1982).

Laboratory tests carried out by Doering and Willis (1975) indicated that a saturated gypsum solution did not improve the hydraulic conductivity of sodic mine spoil. Work done by the Northern Great Plains Research Centre (ARS and NDSU Staff 1977) recorded hydraulic conductivities of sodic overburden leached with a saturated gypsum

solution at 2.5 cm year^{-1}. A second study suggested that gypsum, when used with topsoil, slowed or inhibited increases in sodium levels due to upward migration.

Calcium chloride ($CaCl_2$) is a very water soluble chemical and produces a leaching solution of high electrolyte concentration. Such a solution increases water intake into sodic spoil and is efficient in replacing sodium in soils with high SAR values (Prather et al. 1978).

Alperovitch and Shainberg (1973) found that flow rates through sodic material depended on the concentration of $CaCl_2$ in the applied solution, and that the higher the concentration of $CaCl_2$, the higher the flow rate. Treatments using $CaCl_2$ were most efficient in leaching excess salts and replacing sodium when concentrated in a small volume of solution. Results indicated that with increasing concentrations of the $CaCl_2$ solution, the affinity of the soil for calcium increased and was responsible for the high efficiency in replacing adsorbed sodium from the soil.

The addition of $CaCl_2$ to sodic material by either surface placement or in a solution is superior to the incorporation of the material into the soil (Magdoff and Bresler 1973). If $CaCl_2$ is scarce but water plentiful, then a solution treatment is the most practical reclamation procedure. If on the other hand, water is scarce and the $CaCl_2$ salt plentiful, then top placement is the most practical reclamation procedure.

Fertilizers have no direct effect on the improvement of sodic material but they may correct the unbalanced nutrient status usually associated with high levels of sodium (Richards 1954). By promoting plant growth they increase the beneficial effects of organic matter and plant roots (Fyles 1982).

The use of chemical amendments in the reclamation of sodic mine spoil is often considered secondary because low precipitation results in a slow rate of chemical reaction and reduces subsequent beneficial effects (ARS and NDSU Staff 1977). However, the use of a combination of chemical and physical amendments may lead to a greater success, particularly where suitable topsoil is available.

3. STUDY AREA

3.1 LOCATION

The plots were located on a portion of a derelict coal strip mine at a site known as Bow City (Fig. 1). Bow City lies along the north bank of the Bow River, approximately 40 km southwest of Brooks, Alberta, in the Eastern Alberta Plains. The legal description of the area is SW 1/4 Sec. 14, Sec. 15, and E 1/2 Sec. 16, Twp. 17. Rge. 17, W4M. The total area of the derelict Bow City mine area is 108 ha. The plots occupied an area of 3420 m^2 (0.3 ha.).

3.2 CLIMATE

The climate of the area is classified as being semi-arid (Kuijt 1972). The mean annual temperature ranges from a low of -9°C in January to a high of 19°C in July. The average annual precipitation is approximately 30 cm. Yearly totals vary from 15 to 65 cm, with most of the precipitation occurring in the month of June.

3.3 VEGETATION

Semi-arid temperatures limit plant development to short mixed prairie grassland-shrub communities. Dominant grass species are: western wheatgrass (Agropyron smithii), crested wheatgrass (Agropyron cristatum), June grass (Koelenia gracilis), and blue grama (Boutela gracius) (Fletcher and Sharp 1972). Tree growth is very scarce and is limited to wet depressional areas (Brocke 1976). At Bow City a few stands of aspen poplar (Populus tremuloides) are located in these areas.

3.4 GEOLOGY

At one time Bow City was covered by the Laurentide Ice Sheet (Bowser and Peters 1960). As a result glacial till was deposited as a mantle over the area. The depth of the till varies from one location to another. Alluvial and aeolian deposits, in conjunction with the glacial till, are the surficial parent materials from which soils in the Bow City area have developed.

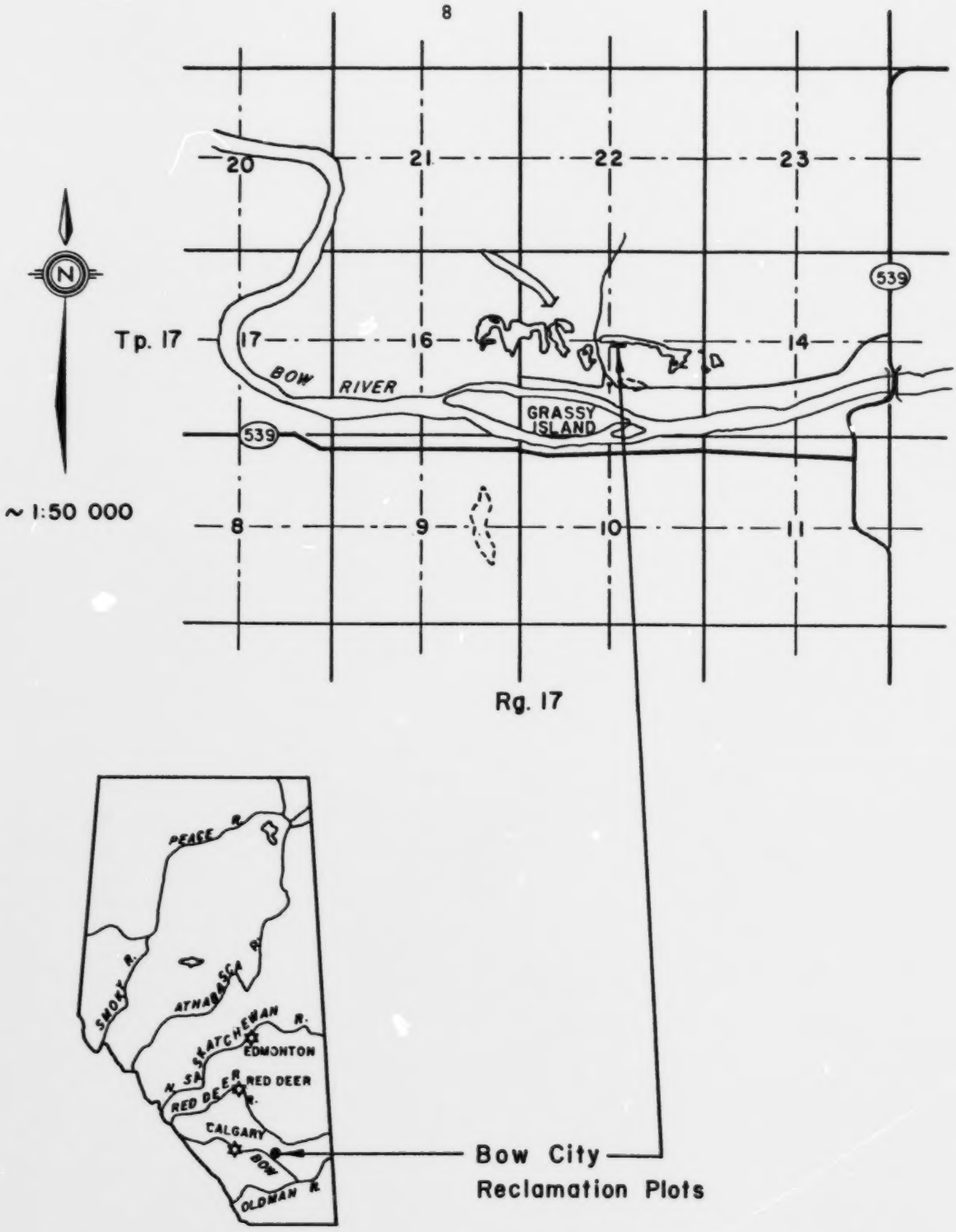

Figure 1. Location of the Bow City reclamation plots.

The bedrock formation underlying the surficial deposits is the Bearpaw Formation. This formation is entirely of late Cretaceous age, and is the thickest formation in southeastern Alberta (Byrne and Parvolden 1959). At Bow City this formation was mined for coal.

Marine shales comprise most of the Bearpaw Formation and are accompanied by numerous sandstone and bentonite beds. The abundance of clay minerals in the clay size fraction of the formation is: montmorillonite, illite, and chlorite. Quartz is also present in all samples. The formation has a relatively high concentration of salts with calcium and sodium sulphates predominating (Loranger and Gleddie 1953).

3.5 SOILS

Bow City lies in the Bow River Valley in the Brown Soil Zone. Native soils in the valley differ from the surrounding upland area, in that they belong to the Chernozemic Order of soils and have developed on alluvial sand overlying till at a depth of approximately 1.2 m (Brocke 1976). These sandy loam textured Calcareous Brown Chernozems are used for pasture land under dry land conditions but have been rated by the Canada Land Inventory as Class 1 soils for irrigation (Brocke 1976).

Soils on the upland area surrounding the Bow River Valley have formed on residual material (Bearpaw Formation), and thin till deposits since much of the till in the region has been removed through erosion (Brocke 1976). These soils are Brown Solonetzic soils. The Brown Solonetzic soils in the Bow City area are normally used as pasture land.

4. MATERIALS AND METHODS

4.1 EXPERIMENTAL DESIGN

The trial site was selected on a levelled mine area near a source of water for irrigation. Two separate trials were set up as split-plot experiments (Fig. 2). The two experiments were similar with the exception that only one was irrigated.

Each experiment consisted of three replicates, of seven treatments each. Each plot was 36 m^2 with a buffer area of 1 m between plots. Each replicate was separated by a buffer of 3 m. The experiments were set up side-by-side with a 25 m wide strip left between them.

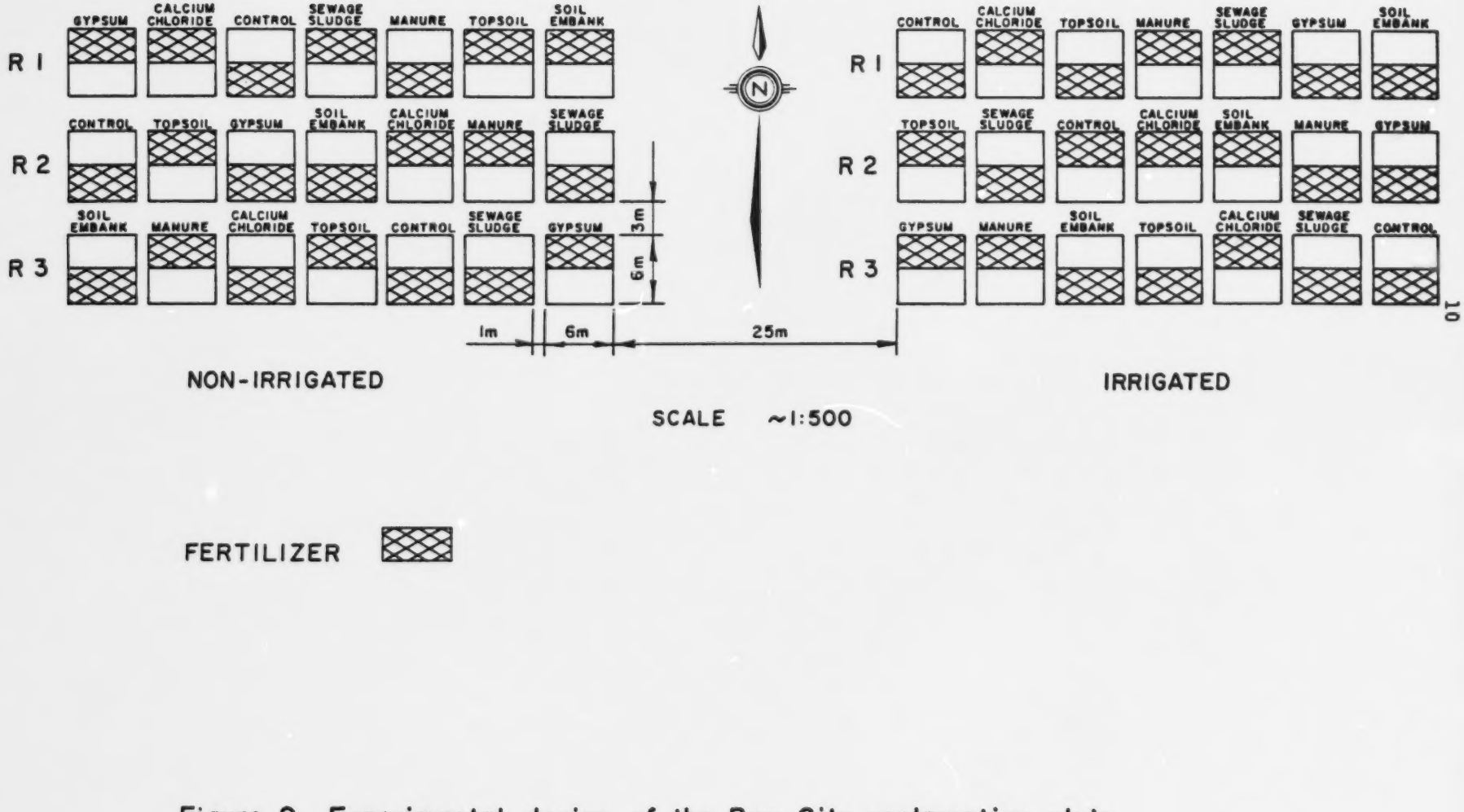

Figure 2. Experimental design of the Bow City reclamation plots.

Seven treatments were randomly assigned to each replicate in September 1976. The treatments consisted of: (1) control (sodic spoil); (2) cow manure applied at 50 dry t ha^{-1} and incorporated to a depth of 10 cm, (3) sewage sludge applied at 38 dry t ha^{-1} and incorporated to a depth of 10 cm; (4) calcium chloride ($CaCl_2$) applied at 6600 kg ha^{-1} and incorporated to a depth of 10 cm; (5) gypsum ($CaSO_4$) applied at 6600 kg ha^{-1} and incorporated to a depth of 10 cm; (6) topsoil applied to the surface to a depth of 15 cm; and (7) spoil embankments built to a height of 35 cm. Chemical analyses of the treatments are listed in Appendix 9.1.

4.2 SEEDING, FERTILIZATION, IRRIGATION AND WEED CONTROL

One half of each plot was fertilized with 50 kg ha^{-1} N and 95 kg ha^{-1} P in 1976. In October of 1978, an additional 50 kg ha^{-1} N was applied.

Cougar Fall Rye was seeded at 15 kg ha^{-1} in September 1976. In November, a grass and alfalfa mixture was seeded at the following rate: Russian Wild Rye at 2.2 kg ha^{-1}, Nadan Crested Wheat Grass at 0.8 kg ha^{-1}, Fairway Crested Wheat Grass at 0.6 kg ha^{-1}, and Rambler Alfalfa at 2.2 kg ha^{-1}. Since the grass and alfalfa seeded in 1976 did not germinate, only fall rye was seeded in September 1977 at a rate of 50 kg ha^{-1}. Fall rye was again seeded at 40 kg ha^{-1} during August 1978 along with 10 kg ha^{-1} of Slender Wheat Grass.

After seeding in the fall of 1976, approximately 10 cm of water was applied to both the irrigated and non-irrigated plots. Thereafter, irrigation was limited to the irrigated plots. Due to the sodic conditions, irrigation was limited to approximately 0.6 cm hr^{-1}. Irrigation was periodic due to the occurrence of runoff caused by dispersion of the spoil. Irrigation was used to promote germination, plant establishment, and leaching, rather than meet plant requirements. Approximately 15 cm of water was applied during 1977. Due to reasonably good soil moisture conditions, no irrigation was undertaken in 1978. Irrigation recommenced in 1979.

Weed growth in the plot area consisted of primarily kochia (Kochia scoparia) and was controlled with 2,4-D amine. The plot area was fenced to prevent damage from cattle.

4.3 SOIL SAMPLING AND ANALYSES

Each plot was sampled three times in 15 cm increments from 0 to 60 cm during 1978, 1981, and 1984. Soil pH was determined on a water-saturated soil paste. Electrical conductivity (EC) and water soluble ions were determined on the paste extracts: sodium (Na) by flame photometry, calcium (Ca) and magnesium (Mg) by atomic adsorption, and chloride (Cl) by Technicon colorimetry. The soil analytical methods are detailed in Appendix 9.2. The results of the analyses performed on each of the samples are listed in Appendix 9.3.

4.4 PLANT SAMPLING

After the plants had stopped growing and started to stem cure, vegetation samples were taken in the summers of 1980, 1981, and 1983. Two samples were taken from each plot representing the fertilized and unfertilized areas using a ring with an area of 0.25 m^2. The ring was randomly placed on the soil surface. All vegetation in the ring was cut 2 cm from the ground surface, collected, oven dried at 40^{o}C and then weighed. Yield results are listed in Appendix 9.4.

4.5 STATISTICAL ANALYSES

All data were analyzed through a split-plot analysis of variance (ANOVA) with year, depth and fertilizer as sub-plot factors. Treatment was a whole-plot factor. Separate ANOVA's were run for the irrigated and non-irrigated plots as they were treated as belonging to two separate experiments in the research design.

Significant differences were pinpointed by performing Tukey's Tests on those parameters sharing significant F values. If the ANOVA for depth was significant, then the data were tested for linear, quadratic and cubic trends. Results of the statistical analyses are listed in Appendix 9.5.

5. RESULTS

The fertilizer treatment had no significant effects on either the soil or plant variables, so will not be discussed further. The sewage sludge, manure, control and soil embankment treatments will also not be discussed due to a lack of significant effects. Only those parameters significantly affected by either of the topsoil, $CaCl_2$, or gypsum treatments will be discussed further. Table 1 summarizes the significant effects of treatment, depth and year on sat.%, pH, EC, Ca, Mg, Na, SAR, Cl and yield. This table should be referred to when reading sections 5.1 to 5.3.

5.1 TOPSOIL TREATMENT

5.1.1 Non-Irrigated

Both the topsoil and $CaCl_2$ treatments reduced the sat.% of the 0 to 15 cm depth. Mean values were 74% for topsoil and $CaCl_2$, and 118% for the other treatments. In 1978 and 1981, values for sat.% followed similar trends with depth (Table 2). The sat.% increased from the surface down to 45 cm, and then decreased down to 60 cm. In 1984 there was a linear increase only and the SAR increased from 72 at the soil surface to 157 at 60 cm.

Topsoil reduced the SAR of the surface 15 cm in 1978 only. The SAR was 16 for topsoil and a mean of 27 for the other treatments. In 1978 and 1981, the SAR increased from the surface down to 30 cm, and then decreased (Table 2). In 1984, the SAR increased down to 45 cm and then decreased.

There were no significant differences between treatments in 1980 for yield. The mean yield was 5.0 g 0.25 m^{2-1}. In 1981 and 1983, the topsoil treatment produced the highest yields. Yields in g 0.25 m^{2-1} were 74.1 and 41.9. Mean yields for the other treatments were 21.3 in 1981 and 5.0 in 1984.

Table 1. Significant effects of treatment, depth and year on sat.%, pH, Ec, Ca, Mg, Na, SAR, Cl, and yield.*

	sat.%			pH			EC (dS m^{-1})			Ca (me L^{-1})			Mg (me L^{-1})			Na (me L^{-1})			SAR			Cl^{-} (me L^{-1})			Yield (g 0.25 m$^{2-1}$)		
	78	81	84	78	81	84	78	81	84	78	81	84	78	81	84	78	81	84	78	81	84	78	81	84	78	81	84
Non-Irrigated																											
Topsoil	↑0-15 ↑45-60	↑0-15 ↑45-60	↑0-15 ↑60																↑0-15 ↑30-60	↑30-60	↑45-60					highest	highest
$CaCl_2$	↑0-15 ↑45-60	↑0-15 ↑30-60	↑0-15 ↑60	↑0-15	↑0-15	↑0-15	↑15-30	↑15-30	↑15-30	↑0-15 ↑60	↑0-15 ↑60	↑0-15 ↑60				↑15-30	↑15-30	↑15-30	↑0-15 1978 ↑45-60	↑45-60	↑45-60	↑all	highest in 1984 0-15 ↑all	↑all ↑60			
Gypsum							↑45-60		↑60	↑0-15 ↑45-60	↑0-15 ↑60	↑0-15 ↑45-60	↑0-15 ↑60	↑0-15	↑0-15 ↑45-60	↑45-60		↑60									
Irrigated																											
Topsoil	↑0-15 30 same 45 ↑60	↑from 78 ↑60	↑0-15 ↑60							↑60	↑60	↑60	↑60	↑60	↑60				↑0-15 ↑45-60	↑0-15 ↑from 78 ↑60	↑0-15 ↑30-45 ↑60				highest	highest	highest
$CaCl_2$	↑60		↑0-15 ↑60	↑0-15					↑45-60 1981 ↑30-60	↑0-15 ↑60	↑60	↑0-15 ↑60	↑60	↑60	↑60	↑45-60		↑45-60 1981 ↑30-60	↑0-15 ↑45-60	↑0-15 ↑60	↑0-15 ↑60	↑all	↑all ↑30-60	↑all ↑30-60 1981 ↑45-60	highest	highest	
Gypsum				↑0-15		↑0-15 1981	↑0-15	↑60	highest ↑0-15 ↑60	↑0-15 ↑30-60	lowest ↑0-15 ↑60		↑30-60		highest ↑0-15	↑0-15 ↑45-60		highest ↑0-15 ↑60	↑30 same as 45 ↑60	highest in 1981	↑0-15 ↑30 same as 45 ↑60						

↑ Increased

↓ Decreased

* Significant at $p<0.05$.

Table 2. Trends with depth over time for the topsoil treatment.

Parameter	Year	Depth (cm)				Trend* (%)**		
		0-15	15-30	30-45	45-60	L	Q	C
Non-Irrigated								
Sat.%	78	56	90	113	107	79	19	0
	81	71	114	115	109	67	32	0
	84	72	116	133	157	100	0	0
SAR	78	16	29	28	27	47	47	0
	81	21	33	31	29	24	69	0
	84	20	34	35	32	47	50	0
Irrigated								
Sat.%	78	59	96	96	114	84	9	9
	81	91	109	121	122	100	0	0
	84	74	114	133	141	89	11	0
SAR	78	16	26	27	27	11	23	0
	81	23	30	32	33	100	0	0
	84	19	33	24	34	62	30	0
Ca (me L^{-1})	78	6.74	2.84	2.05	1.85	75	23	0
	81	4.81	2.16	1.68	1.45	73	22	0
	84	6.25	6.09	2.28	1.71	100	0	0
Mg (me L^{-1})	78	1.94	0.80	0.58	0.48	77	20	0
	81	1.58	0.73	0.57	0.51	73	23	0
	84	1.84	1.03	0.68	0.45	100	0	0

* Linear (L), quadratic (Q), and cubic (C) trends are significant at $p<0.05$.

** Proportion of variance due to depth accounted for by the respective trends.

5.1.2 Irrigated

In 1978 topsoil decreased the sat.% of the surface 15 cm. The sat.% was 59% for topsoil and a mean of 105% for the remaining treatments. In 1984 both topsoil and $CaCl_2$ decreased the sat.%. Mean percentages were 84% for topsoil and $CaCl_2$, and 128% for the other treatments. Although there were no differences between treatments in 1981, there was an increase in the sat.% within the surface 15 cm (91%) from 1978 (59%) for the topsoil treatment. The sat.% increased from the soil surface down to 60 cm for all three years monitored (Table 2). The only difference between years was that during 1978, values were similar at the 15 to 30 and 30 to 45 cm depths.

In 1978 and 1981, both topsoil and $CaCl_2$ reduced the SAR of the surface 15 cm. Mean values for both years respectively were 17 and 18 for topsoil and $CaCl_2$, and 26 and 32 for the other treatments. In 1984, topsoil, $CaCl_2$ and gypsum reduced the SAR of the surface 15 cm. Mean values were 20 for the first three treatments previously listed, and 28 for the remaining treatments. The SAR was higher in 1981 (23) than 1978 (16) for the topsoil treatment at the 0 to 15 cm depth.

There were linear increases in SAR with depth in the profile for each year sampled (Table 2). In 1978 values increased from the surface down to 45 cm. In 1981 there was linear increase from the surface down to 60 cm, and in 1984 the SAR increased down to 30 cm, decreased to 45 cm and then increased down to 60 cm.

Concentrations of soluble Ca and Mg decreased from the soil surface down to 60 cm for each of the three years monitored (Table 2).

The topsoil and $CaCl_2$ treatments had the highest yields in 1980 and 1981, while topsoil alone had the highest yield in 1983. Mean yields in g 0.25 m^{2-1} for $CaCl_2$ and topsoil with respect to the other treatments were 42.0 and 11.5 (1980), and 89.6 and 20.1 (1981). Topsoil had a yield of 23.3 in 1983 and the other treatments had a mean yield of 3.3.

5.2 $CaCl_2$ TREATMENT

5.2.1 Non-Irrigated

Both the $CaCl_2$ and topsoil treatments reduced the sat.% of the surface 15 cm from 118% to 74% with respect to the other treatments. Various trends occurred with depth for each of the three years monitored (Table 3). In 1978 the sat.% increased from the surface down to 45 cm then decreased. In 1981 the same trend occurred except values increased down to 30 cm and then decreased. In 1984 the sat.% increased in a linear fashion from the surface down to 60 cm.

The use of $CaCl_2$ decreased the pH in the surface 15 cm. Mean values were 7.04 for $CaCl_2$ and 7.53 for the remaining treatments.

Both the $CaCl_2$ and manure treatments increased the EC of the 15 to 30 cm depth. Mean values were 6.27 dS m^{-1} for $CaCl_2$ and manure, and 4.24 dS m^{-1} for the remaining treatments.

$CaCl_2$ and gypsum both increased the concentration of soluble Ca within the surface 15 cm. Concentrations in me L^{-1} were 13.09 for $CaCl_2$ and gypsum, and 2.24 for the remaining treatments. There was a linear decrease in soluble Ca from the surface down to 60 cm for each year monitored (Table 3).

Both the $CaCl_2$ and manure treatments increased concentrations of soluble Na in the 15 to 30 cm depth. Mean values were 63.05 me L^{-1} for $CaCl_2$ and manure, and 43.50 me L^{-1} for the remaining treatments.

The SAR increased within the surface 15 cm in 1981 (30) from 1978 (21). This parameter also had similar trends with depth for each year monitored (Table 3). The SAR increased from the surface down to 45 cm and then decreased.

Concentrations of Cl were increased at all depths using $CaCl_2$. Mean concentrations for each depth using $CaCl_2$ were 34.99 (0 to 15 cm), 29.46 (15 to 30 cm), 24.86 (30 to 45 cm), and 28.89 (45 to 60 cm) me L^{-1} respectively. Corresponding concentrations for the remaining treatments were 1.07, 0.09, 0.98 and 1.58 me L^{-1} respectively. There was more soluble Cl within the surface 15 cm in 1984 (40.58 me L^{-1}) than 1981

Table 3. Trends with depth over time for the $CaCl_2$ treatment.

Parameter	Year	Depth (cm) 0-15	15-30	30-45	45-60	Trend* (%)** L	Q	C
Non-Irrigated								
Sat.%	78	74	101	118	106	55	43	0
	81	82	108	107	98	0	100	0
	84	88	106	113	139	100	0	0
Ca (me L^{-1})	78	15.85	7.99	4.80	4.28	100	0	0
	81	9.63	8.99	7.08	3.44	100	0	0
	84	13.70	8.84	6.58	3.72	100	0	0
SAR	78	21	34	37	36	74	23	0
	81	30	39	40	38	56	44	0
	84	27	35	44	39	65	34	0
Cl (me L^{-1})	84	40.64	28.21	26.05	15.25	100	0	0
Irrigated								
Sat.%	78	85	101	103	109	57	33	0
	84	94	110	128	131	100	0	0
EC (dS m^{-1})	81	4.74	3.93	3.78	3.60	100	0	0
	84	8.53	5.86	4.80	3.90	90	9	0
Ca (me L^{-1})	78	11.81	2.93	3.57	3.09	50	53	0
	81	6.24	2.48	1.85	1.77	69	29	0
	84	9.37	5.90	3.40	2.40	100	0	0
Mg (me L^{-1})	78	1.91	0.80	0.58	0.48	77	20	0
	81	1.21	0.75	0.62	0.56	78	23	0
	84	2.07	1.97	1.17	0.91	100	0	0
Na (me L^{-1})	78	42.07	44.97	56.14	46.82	100	0	0
	84	39.99	66.58	65.14	59.75	45	53	0
SAR	78	17	32	37	35	70	30	0
	81	22	38	41	43	81	17	0
	84	17	32	45	48	92	7	0
Cl (me L^{-1})	81	8.90	17.72	13.33	10.99	76	20	0
	84	10.90	24.18	25.95	21.28	48	51	0

* Linear (L), quadratic (Q), and cubic (C) trends are significant at $p<0.05$.

** Proportion of variance due to depth accounted for by the respective trends.

(29.36 me L^{-1}). In 1984 there was a linear trend with increasing depth (Table 3). Concentrations of Cl decreased from the surface down to 60 cm.

5.2.2 Irrigated

Both topsoil and $CaCl_2$ reduced the sat.% of the surface 15 cm in 1984 (sec. 5.1.2). In both 1978 and 1984 values for sat.% increased from the soil surface down to 60 cm (Table 3).

In 1978, both the $CaCl_2$ and gypsum treatments decreased soil pH within the surface 15 cm. Mean values were 7.39 for $CaCl_2$ and gypsum, and 7.63 for the remaining treatments.

Salt concentrations increased at the 45 to 60 cm depth in 1984 (5.99 dS m^{-1}) from the same depth in 1981 (4.02 dS m^{-1}). In 1984 the EC had significant trends with depth (Table 3). Values increased from the soil surface down to 30 cm, and then decreased down to 60 cm.

The $CaCl_2$ and gypsum treatments increased the concentrations of soluble Ca in 1978 and 1984 within the 0 to 15 cm depth. Concentrations with respect to the other treatments were 10.75 and 3.56 me L^{-1} respectively in 1978, and 11.83 and 4.28 me L^{-1} in 1984. Concentrations of soluble Ca and Mg decreased from the soil surface to 60 cm (Table 3).

Concentrations of soluble Na increased in 1984 (59.75 me L^{-1}) from those measured in 1981 (39.08 me L^{-1}) within the 45 to 60 cm zone. Concentrations also followed trends with depth (Table 3). In 1978, concentrations increased down to 45 cm and then decreased. In 1984 concentrations increased down to 30 cm and then decreased.

As was mentioned previously, the topsoil and $CaCl_2$ treatments reduced the SAR within the surface 15 cm (sec 5.1.2). The SAR also followed trends with depth (Table 3). In 1978 the SAR increased down to 45 cm and then decreased. In 1981 and 1984 values increased from the soil surface down to 60 cm.

$CaCl_2$ increased soluble Cl at each depth monitored. Mean concentrations in me L^{-1} for $CaCl_2$ and the other treatments for each depth were 9.89 and 0.67, 19.96 and 0.54, 19.7 and 0.53, and 16.24 and 0.51 respectively. At the 30 to 45 and 45 to 60 cm depths, Cl

concentrations increased in 1984 from 1981. From 30 to 45 cm, concentrations were 13.28 me L^{-1} in 1981 and 25.96 me L^{-1} in 1984. At the 45 to 60 cm depth, concentrations were 10.96 me L^{-1} in 1981 and 21.28 me L^{-1} in 1984. In 1981 concentrations of Cl increased down to 30 cm and then decreased (Table 3). In 1984 concentrations increased down to 45 cm and then decreased.

As was mentioned previously, topsoil and $CaCl_2$ had the highest yields in both 1980 and 1981 (sec. 5.1.2).

5.3 GYPSUM

5.3.1 Non-Irrigated

In 1978, values for EC decreased from the soil surface down to 45 cm and then increased down to 60 cm (Table 4). In 1984 values decreased in a major linear fashion from the soil surface down to 60 cm.

The gypsum and $CaCl_2$ treatments significantly increased soluble Ca concentrations within the surface 15 cm (sec. 5.2.1). Soluble Mg concentrations were also increased at that depth, but by the gypsum treatment only. Concentrations in me L^{-1} were 2.82 for gypsum and a mean value of 0.98 for the other treatments.

Both soluble Ca and Mg had major linear and minor quadratic trends with depth (Table 4). In 1978 Ca concentrations decreased from the soil surface down to 45 cm and then increased down to 60 cm. Mg concentrations decreased from the soil surface down to 60 cm. Ca concentrations followed a similar trend in 1981. In 1984 concentrations of both cations decreased down to 45 cm, and then increased down to 60 cm.

In 1978 concentrations of soluble Na decreased from the soil surface to 45 cm, and then increased down to 60 cm (Table 4). In 1984, there was a linear decrease in concentrations of soluble Na with increasing depth in the plots.

5.3.2 Irrigated

Both gypsum and $CaCl_2$ treatments decreased the soil pH within the surface 15 cm in 1978 (sec. 5.2.2). The use of gypsum also decreased the pH at this depth from 7.54 in 1981 to 7.10 in 1984.

Table 4. Trends with depth over time for the gypsum treatment.

Parameter	Year	Depth (cm) 0-15	15-30	30-45	45-60	Trend* (%)** L	Q	C
Non-Irrigated								
EC (dS m^{-1})	78	6.67	5.03	3.74	4.42	69	30	0
	84	7.63	5.32	3.93	3.88	100	0	0
Ca (me L^{-1})	78	12.80	5.21	2.66	4.37	61	30	0
	81	11.03	4.34	3.54	3.52	65	26	0
	84	15.53	4.37	2.28	2.45	71	27	0
Mg (me L^{-1})	78	2.62	1.54	1.41	1.21	74	25	0
	84	3.16	1.14	0.56	0.72	71	27	0
Na (me L^{-1})	78	65.16	50.74	37.04	44.11	70	27	0
	84	76.25	55.28	40.45	39.74	100	0	0
Irrigated								
EC (dS m^{-1})	81	4.74	3.93	3.78	3.60	100	0	0
	84	8.53	5.86	4.80	3.90	90	9	0
Ca (me L^{-1})	78	9.69	2.62	2.64	3.21	55	39	8
	84	14.29	4.62	3.56	2.25	76	20	0
Mg (me L^{-1})	78	2.11	0.65	0.73	0.93	45	47	0
	84	4.32	1.39	1.08	0.60	76	20	4
Na(me L^{-1})	78	54.68	43.19	42.42	47.10	0	100	0
	84	83.16	61.03	49.08	39.56	100	0	0
SAR	78	25	34	34	36	66	21	13
	84	25	36	36	34	44	52	0

* Linear (L), quadratic (Q), and cubic (C) trends are significant at $p<0.05$.

** Proportion of variance due to depth accounted for by the respective trends.

In 1978 and 1984, gypsum increased the EC within the surface 15 cm. Mean values with respect to the other treatments were 5.71 and 3.73 dS m^{-1} in 1978, and 8.52 and 4.48 dS m^{-1} in 1984. The EC was highest within this depth in 1984 (8.53 dS m^{-1}) as compared to 1978 and 1981 (5.23 dS m^{-1}). Values for EC had linear trends with depth in 1981 and 1984 (Table 4). The EC decreased from the soil surface down to 60 cm for both years.

In 1978 and 1984 both gypsum and $CaCl_2$ increased concentrations of soluble Ca within the surface 15 cm (sec. 5.2.2). Gypsum also increased soluble Mg concentrations in 1984. Mean concentrations in me L^{-1} for gypsum and the other treatments were 4.32 and 1.47 respectively. Within this depth, Ca concentrations were lowest in 1981 (2.84 me L^{-1}) and Mg concentrations were highest in 1984 (4.32 me L^{-1}). Both cations had similar trends with depth in 1978 and 1984 (Table 4). In 1978, concentrations decreased down to 30 cm and then increased down to 60 cm. In 1984 concentrations decreased from the soil surface down to 60 cm.

Soluble Na increased in 1978 and 1984 within the surface 15 cm. Concentrations with respect to the other treatments in me L^{-1} were 54.68 and 34.79 in 1978, and 83.16 and 43.27 in 1984. Concentrations of Na were the highest in 1984 within this depth (83.16 me L^{-1}) as compared to 1981 and 1978 (51.06 me L^{-1}). Soluble Na concentrations decreased from the soil surface down to 45 cm and then increased down to 60 cm in 1978 (Table 4). In 1984 there was a major linear decrease from the soil surface down to 60 cm.

In 1984, gypsum along with $CaCl_2$ and topsoil decreased the SAR within the surface 15 cm (sec. 5.1.2). Values for the SAR were highest within this depth in 1981 (35) as compared to 1978 and 1984 (25). In 1978 the SAR increased down to 30 cm, remained the same at 45 cm and then increased down to 60 cm (Table 4). In 1984, the same trend occurred except that the SAR decreased after 45 cm.

6. DISCUSSION

The objectives of the reclamation trials were to: (1) assess the ability of various treatments in reducing the effects of high levels of sodium in the spoil, and (2) establish a permanent and useful vegetative cover on the spoil. The results of the trials will be discussed with these two objectives in mind.

6.1 NON-IRRIGATED TRIALS

The topsoil treatment was the most effective non-irrigated trial in terms of reducing the effects of sodium and establishing a vegetative cover. A surface 15 cm application of topsoil provided improved conditions for germination and growth as reflected in the yields of 1981 and 1983. The topsoil was non-saline (EC 1.9 dS m^{-1}) and non-sodic (SAR 0.5), with a sat.% of 55 and a pH of 7.7. Adding the topsoil as a surface amendment to the spoil decreased the sat.% for the length of the experiment and the SAR for the first year, in the surface 15 cm. Topsoil was the only treatment able to decrease the SAR. Trends with depth for the sat.% and SAR show the addition of topsoil and vegetative growth to have promoted some leaching. By 1984 there was a major linear increase for the sat.% with depth, and the maximum annual SAR value moved downwards from 30 to 45 cm.

The major drawback with the use of topsoil was the re-sodification of the surface 15 cm. Topsoil was only able to reduce the SAR in 1978. Therefore, upward movement of salts occurred. This is a problem with the application of topsoil directly over sodic spoil, and has been well documented in the literature (sec. 2.2.1).

$CaCl_2$ followed topsoil as an effective non-irrigated reclamation treatment for sodic spoil. Like topsoil, the addition of $CaCl_2$ decreased the sat.% of the surface 15 cm. Unlike topsoil it decreased the pH and increased concentrations of soluble Ca and Cl within the same depth. The addition of high rates of Ca promoted the replacement of Na on the soil exchange complex, flocculation, and leaching. Maximum leaching occurred down to 30 cm, as was seen by increased values for EC and soluble Na and Cl in the 15 to 30 cm depth.

Therefore, $CaCl_2$ was able to promote the movement of Na from the surface 15 cm, downwards. There was also evidence of leaching below 30 cm. By 1984 there was a major linear increase in the sat.% from the surface to 60 cm, and concentrations of Cl increased in a linear fashion at all depths. Soluble Ca also followed a linear trend in that it decreased from the surface to 60 cm. SAR values reflected downward movement as values consistently increased to 45 cm and then decreased.

Even though $CaCl_2$ was able to reduce the effects of high Na, there was no effective permanent vegetative cover established. For each of the three years monitored $CaCl_2$ always had the second highest yields, but they were never significantly different from the control treatment.

Even though gypsum had a number of significant effects on the various soil parameters, in the short term it was unable to reduce the effects of excess Na or promote growth. The various parameters monitored indicated a concentration of salts within the soil surface. This may have been due to the low solubility of gypsum resulting in slow dissolution over time. In 1978 minimum values for the EC and soluble Na were at 45 cm: values decreased to 45 cm and then increased to 60 cm. In 1984, there was a major linear decrease from the soil surface to 60 cm for both parameters. Concentrations of soluble Ca and Mg were highest within the surface 15 cm for the length of the project. In general, gypsum had the third highest yields for each year measured, but like the $CaCl_2$ treatment they were not significantly different from the control plots.

6.2 IRRIGATED TRIALS

Topsoil was the most effective irrigated treatment in terms of reducing the effects of high sodium and promoting growth. As was explained in the non-irrigated section, a surface application of topsoil provided a root zone with reduced sat.% and SAR values. This resulted in highest yields for all the years monitored. Unlike the non-irrigated treatment, leaching was much more obvious. Concentrations of both Ca and Mg decreased in a major linear fashion to 60 cm, and values for sat.%

increased in a linear fashion to 60 cm. Maximum annual values for the SAR were also at much lower depths: 45 cm in 1978, and 60 cm in 1981 and 1984.

The topsoil treatment under irrigated conditions did get some upward movement of salts. In 1981 the SAR was increased in the surface 15 cm as compared to 1978. Therefore, upward movement of salts may become a problem when irrigation stops.

$CaCl_2$ followed topsoil as an effective reclamation technique for sodic spoil. $CaCl_2$ only decreased the sat.% of the surface 15 cm in 1984, but it also increased soluble Ca concentrations within that depth for the length of the experiment. The excess Ca replaced Na which was leached downwards as was reflected in the decreased SAR values within the top 15 cm. $CaCl_2$ also promoted leaching and moved excess salts down to 60 cm. Both the EC and concentrations of soluble Na and Cl increased within the 45 to 60 cm depth in 1981. In terms of a general trend, by 1984 these parameters increased from the soil surface down to 30 cm, and then decreased. Linear trends which increased from 1978 to 1984 and reflected downward movement were values for the sat.% and SAR which increased with depth, and concentrations of Ca and Mg which decreased with depth. Cl concentrations were increased at all depths.

As a result of the reduced SAR and EC values, and increased flocculation, vegetation was able to establish. Yields were similar to those of topsoil in 1980 and 1981.

Similarly to the non-irrigated treatment, gypsum was unable to establish an effective permanent vegetative cover or effectively reduce the effects of Na, and salts concentrated within the soil surface. The addition of gypsum decreased the pH and increased concentrations of Ca within the surface 15 cm. In 1984 the values for EC and concentrations of Mg and Na were highest within the surface 15 cm. Trends with depth also reflected surface salt concentrations: values for the EC decreased in a strong linear fashion from 0 to 60 cm; concentrations of Ca and Mg

decreased to 30 cm then increased in 1978, and in 1984 decreased linearly to 60 cm; concentrations of Na decreased to 45 cm then increased in 1978, and in 1984 decreased to 60 cm; and in 1978 SAR values increased to 60 cm, while in 1984 they increased to 45 cm then decreased.

6.3 YIELD

Bow City is situated within Agricultural Reporting Area #1. The average forage yield for this area for the same years as the plots were harvested was 3.8 t ha^{-1} (Table 5). Even though the topsoil and $CaCl_2$ treatments for the irrigated plots, and the topsoil treatment for the non-irrigated plots increased yields over the control plots, the yields were still much less than that for the local area. Therefore, even though some of the treatments promoted growth, the growth was less than that for local undisturbed areas. For example, the highest plot yields were 2.2 t ha^{-1} for the irrigated topsoil treatment, as compared to 3.8 t ha^{-1} from the local area.

Table 5. Comparison of mean plot yields to local yields for the years 1980, 1981 and 1983.

Treatment	Yield (t ha^{-1}) Irrigated	Non-Irrigated
Control	0.5	0.2
$CaCl_2$	2.0[1]	0.7
Topsoil	2.2[1]	1.8[1]
Cow Manure	0.5	0.5
Sewage Sludge	0.7	0.5
Gypsum	0.5	0.5
Soil Embankment	0.2	0.2
Agricultural Reporting Area #1	3.8	

[1] Significantly increased yields from the control at $p<0.05$.

7. CONCLUSIONS

1. Fertilizer had no effect on plant growth or any of the soil variables monitored.
2. The sewage sludge, manure, and soil embankment treatments were ineffective in amending sodic spoil and promoting vegetative growth.
3. Topsoil was the most effective irrigated and non-irrigated treatment in terms of reducing the high levels of Na and establishing a permanent useful vegetative cover.
4. The upward movement of salts from sodic spoil into topsoil may be a problem under non-irrigated conditions.
5. $CaCl_2$ was the second most effective irrigated and non-irrigated treatment in terms of reducing the high levels of Na and establishing a permanent useful vegetative cover.
6. $CaCl_2$ was the most effective treatment in promoting leaching and therefore the downward movement of salts.
7. Both the irrigated and non-irrigated gypsum treatments were ineffective in the reclamation of sodic spoil in the short term, as they promoted the concentration of salts within the soil surface.
8. All treatments had their largest effects on the 0 to 15 cm depths for both the irrigated and non-irrigated plots.
9. Yields were much lower than adjacent undisturbed areas regardless of the type of reclamation treatment applied.

In general, results of these reclamation trials indicate that when mining for coal in areas containing sodic bedrock, the best method to be used to ensure reclamation seems to be to conserve suitable materials for soil reconstruction. These trials should be conducted under other environmental conditions beside semi-arid to see if the same treatments will be recommended.

8. REFERENCES CITED

Alberta Agriculture. 1981. Soil quality criteria for reclamation of disturbed lands. Alberta Soils Advisory Committee. Edmonton, Alberta. 54 pp.

Alperovitch, N. and I. Shainberg. 1973. Reclamation of alkali soils with $CaCl_2$ solutions. From: Hadas, A. 1973. Physical aspects of soil water and salts in ecosystems. Springer-Verlag. New York pp. 432-440.

ARS and NDSU Staff. 1977. North Dakota progress report on reclamation of strip-mined lands: update 1977. Northern Great Plains Research Centre. USDA-SEA-AR. Mandan, North Dakota. 26 pp.

Bower, C.A., L.R. Swarner, A.W. Marsh, and P.M. Tikston. 1951. The improvement of an alkali soil by treatment with manure and chemical amendments. Oregon Agr. Exp. Sta. Tech. Bull. 22. 37 pp.

Bowser, W. and T. Peters. 1942. Soil survey of the Blackfoot and Calgary Sheets. Alberta Soil Survey Bulletin No. 39. Edmonton, Alberta. 66 pp.

Brocke, L. 1976. Inventory characteristics and evaluation of the soil materials at four derelict sites in the great plains region of Alberta. Alberta Environment. Edmonton, Alberta. 27 pp.

Byrne, P. and R. Farvolden. 1959. The clay mineralogy and chemistry of the Bearpaw formation of Southern Alberta. Research Council of Alberta. Bulletin No. 4. Edmonton, Alberta.

Canada Department of Agriculture. 1976. Glossary of terms in soil science. Publication 1459. Ottawa, Ontario. 44 pp.

Doering, E.T. and W.O. Willis. 1975. Chemical reclamation of sodic strip-mined spoils. ARS-NC-20. Preoria, Ill. 8 pp.

Dollhoph, D.J. and E.J. DePuit. 1981. Chemical amendment and irrigation effects on sodium migration and vegetation characteristics in sodic mine soils in the Northern Great Plains. Symposium on surface mining hydrology, sedimentology and reclamation. Univ. of Kentucky. Lexington, Kentucky. pp. 481-485.

Fletcher, R. and T. Sharp. 1972. Southern Alberta: a regional perspective. University of Lethbridge. Lethbridge, Alberta.

Fyles, H. 1982. The reclamation of sodic mine spoils. Paper For Soils 501. University of Alberta. Edmonton, Alberta. 35 pp.

Gee, G.W., Bauer, A., and R.S. Decker. 1978. Physical analysis of overburden materials and mine land soils. In: Schaller, F.W., and P. Sutton, eds. Reclamation of drastically disturbed lands. Amer. Soc. Agronomy. Madison, Wisconsin. pp 665-686.

Hadas, A. 1973. Physical aspects of soil water and salts in ecosystems. Springer-Verlag. New York.

Harron, W.R.A. 1979. The effect of sodium on water movement in a Duagh-Malmo soil association. Unpublished M.Sc. Thesis. University of Alberta. Edmonton, Alberta.

Heald, W.R., Moodie, C.D., and R.W. Leamer. 1950. Leaching and pre-emergence irrigation for sugar beets on saline soils. Wash. Agr. Expt. Sta. Bul. 519. 16 pp.

Industrial Method No. 165-71W. 1972. Hardness in water and wastewater T.I.S. Tarrytown, N.Y.

Industrial Method No. 237-72A. 1977. Simultaneous determination of phosphorous, magnesium, calcium, and potassium in soils. T.I.S. Tarrytown, N.Y.

Industrial Method No. 99-70W/B. 1977. Chloride in water. T.I.S. Tarrytown, N.Y.

Kuijt, J. 1972. Common coulee plants of southern Alberta. University of Lethbridge. Lethbridge, Alberta.

Loranger, D. and E. Gleddie. 1953. Some Bearpaw zones in southwestern Saskatchewan and southern Alberta. Alberta Society of Petroleum Geologists. Edmonton, Alberta.

Luken, H. 1962. Saline soils under dryland agriculture in southeastern Saskatchewan (Canada) and possibilities for their improvement. Plant and Soil. 17:1-65.

Magdoff, F. and E. Bresler. 1973. Evaluation of methods for reclaiming sodic soils with $CaCl_2$. Soil Sci. Soc. Amer. Proc. pp. 441-452.

McKeaque, J.A. ed. 1978. Manual on soil sampling and methods of analysis. Canadian Society of Soil Science. Ottawa, Ontario. 212 pp.

Power, J.F., R.E. Ries, and F.M. Sandoval. 1978. Reclamation of coal-mined land in the Northern Great Plains. J. Soil and Water Cons. 33:69-74.

Power, J.F., F.M. Sandoval, R.E. Ries, and S.D. Merrill. 1981. Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Sci. Soc. Amer. J. 45:124-129.

Prather, R.J., Goertzen, J.O., Rhoades J.D., and H. Frenkel. 1978. Efficient amendment use in sodic soil reclamation. Soil Sci. Soc. Am. J. 42:782-786.

Reeve, R.C., Allison, L.E., and D.F. Peterson. 1984. Reclamation of saline-alkali soils by leaching: Delta area, Utah. Utah Agr. Expt. Sta. Bul. 335. 55 pp.

Regier, H. 1979. Progress report for the Bow City reclamation trials. Alberta Environment. Lethbridge, Alberta.

Richards, L.A. ed. 1954. Diagnosis and improvement of saline and alkaline soils. U.S.D.A. Agriculture Handbook 60. Soil and Water Conservation Research Branch. Agricultural Research Service. U.S.D.A. Washington, D.C. 160 pp.

Rhoades, J.D. 1982. Soluble salts. In: Methods of soil analysis. Part 2. Agronomy 9:167-179. A.S.A. Madison, Wisconsin.

Sandoval, F.M., and W.L. Gould. 1978. Improvement of saline and sodium affected disturbed lands. In Reclamation of drastically disturbed land. ASA-CSSA-SSSA. Madison, Wisconsin. pp. 485-503.

SEA and NDSU Staff. 1979. Reclamation research supplement to "North Dakota progress report on research on reclamation of strip-mined land - update 1977". Northern Great Plains Research Centre. USDA-SEA-AR. Mandan, North Dakota. 16 pp.

White, R.A., and E. de Jong. 1975. Reclamation of salt and oil damaged soils. Sask. Inst. Ped. Pub. M27.

9. APPENDICES

9.1 TREATMENT ANALYSES

The results of the chemical analyses performed on the individual treatments are listed in Tables 6 to 9.

9.2 SOIL ANALYTICAL METHODS

The analytical methods used on the soil samples are listed in Table 10.

9.3 SOIL DATA: 1978 TO 1984

Results of the analyses performed on the soil samples are listed in Tables 11 to 16.

9.4 PLANT DATA: 1980 to 1983

Yield data are listed in Tables 17 and 18.

9.5 RESULTS OF STATISTICAL ANALYSES

Results of the statistical analyses performed on the data are listed in Tables 19 to 34.

Table 6. Characteristics of sodic spoil at Bow City before treatment.

Depth (cm)	Sand (%)	Clay (%)	Texture	Sat.%	EC (dS m^{-1})	SAR	NH_4OAc ext. Ca	Mg	K	Na	CEC (me $100g^{-1}$)
							(me $100g^{-1}$)				
0-15	56	23	SCL	110	4.5	40	13	3.3	0.7	20	31
15-30	58	23	SCL	120	4.5	30	16	3.3	0.7	19	32
30-45	--	--	---	140	2.7	27	14	3.1	0.6	20	29
45-60	--	--	---	120	4.2	37	14	3.1	0.6	21	32

Table 7. Characteristics of topsoil used at Bow City.

	sat.%	pH	EC ($dS\ m^{-1}$)	SAR	Ca	Mg	Na	K	HCO_3	CO_3	Cl	NO_3	SO_4[1]
					($me\ L^{-1}$)								
Sample 1	54	7.6	2.3	0.4	20	6.5	1.5	0.2	5.6	0.1	2.5	6.8	13.0
Sample 2	55	7.8	1.4	0.5	12	4.5	1.3	0.3	6.0	0.2	2.5	3.3	5.9

1 SO_4 determined by ionic difference.

Table 8. Characteristics of the cow manure, sewage sludge, and gypsum used at Bow City.

	Cow Manure[1]	Calgary Sewage Sludge[1]	Gypsum[2]
Sat.%	58.00	86.00	11.00
% TKN	2.47	3.89	ND
% NH_4-N	0.01	0.88	ND
% P	0.63	1.77	0.60
% K	3.33	0.32	0.01
% Ca	2.86	4.77	22.00
% Mg	0.20	1.20	0.01
% Na	0.41	0.10	0.03
Cd (ug g^{-1})	0.50	12.00	6.40
Cu (ug g^{-1})	28.00	880.00	3.10
Fe (ug g^{-1})	4100.00	12,200.00	260.00
Pb (ug g^{-1})	5.00	1520.00	8.30
Mn (ug g^{-1})	230.00	195.00	1.10
Hg (ug g^{-1})	ND	4.90	ND
Ni (ug g^{-1})	10.00	46.00	ND
Zn (ug g^{-1})	94.00	1770.00	41.00

ND - not determined.
Constituents based on a dry weight basis.
1 Excepting TKN and NH_4-N, determinations were made on a perchloric acid digest.
2 Determinations were made on a 1:1000 dilution with water.

Table 9. Characteristics of the irrigation water used at Bow City.

	pH	EC ($dS\ m^{-1}$)	SAR	Ca+Mg	Na	K	HCO_3	CO_3	Cl	SO_4[1]
				($me\ L^{-1}$)						
Aug. 16, 1976	8.6	1.9	9.3	5.6	16.0	0.2	4.5	0.4	0.2	16.0
May 5, 1977	8.5	1.9	7.8	7.4	15.0	0.2	5.1	0.2	0.2	18.0
June 8, 1977	8.6	2.0	8.7	5.9	15.0	0.2	4.6	0.3	0.1	16.0
June 27, 1979	8.7	1.9	7.5	5.6	7.5	0.2	ND	ND	ND	ND

ND not determined.
[1] SO_4 determined by ionic difference.

Table 10. Soil analytical methods.

Parameter	Method	Reference
Saturation Percentage (Sat.%)	saturation extract	McKeaque, J.A. 1978.
Electrical Conductivity (EC)	Wheatstone bridge on saturation extract	McKeaque, J.A. 1978.
pH	pH in water	McKeaque, J.A. 1978.
Sodium (Na)	saturation extract, flame photometry, 0.01 % Li	Rhoades, J.D. 1982.
Calcium (Ca)	saturation extract, Technicon AA II, colorimetry	Industrial Method No. 165-71W. 1972.
Magnesium (Mg)	saturation extract, Technicon AA II, colorimetry	Industrial Method No.237-72A. 1977.
Chloride (Cl)	saturation extract, Technicon AA II, colorimetry	Industrial Method No.99-70W/B. 1977.

Table 11. Means of analyses performed on nonirrigated samples: 1978.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Control	00-15	112.25	7.77	2.74	1.14	0.39	26.24	30.56	---
	15-30	109.42	7.54	3.71	1.65	0.57	36.36	34.58	---
	30-45	113.92	7.67	3.70	3.08	0.83	36.86	30.30	---
	45-60	114.67	7.74	3.39	2.19	0.56	33.28	30.43	---
Calcium Chloride	00-15	73.58	7.12	6.73	15.85	2.35	57.98	20.54	---
	15-30	100.83	6.67	7.01	7.99	1.97	65.91	33.77	---
	30-45	117.50	7.31	5.34	4.80	1.37	58.77	36.64	---
	45-60	106.33	7.26	5.52	4.28	1.21	57.75	36.10	---
Topsoil	00-15	55.58	7.48	2.96	5.72	1.49	26.68	15.84	---
	15-30	89.75	7.42	4.23	3.34	0.79	41.21	28.94	---
	30-45	112.67	7.48	3.50	2.43	0.62	34.53	28.11	---
	45-60	106.83	7.56	3.39	2.60	0.63	33.42	26.90	---
Manure	00-15	109.50	7.90	2.98	2.24	0.73	28.67	27.17	---
	15-30	102.33	7.12	5.11	4.88	1.34	50.76	32.69	---
	30-45	103.75	7.03	4.71	4.77	1.36	45.91	29.99	---
	45-60	118.00	7.35	4.22	5.88	1.38	40.65	41.33	---

(CONTINUED)

Table 11. Concluded.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Sewage Sludge	00-15	110.33	7.72	3.48	2.12	0.67	33.52	28.94	---
	15-30	108.50	7.82	3.41	1.72	0.58	33.95	31.71	---
	30-45	104.83	7.55	3.52	2.31	0.67	35.58	29.65	---
	45-60	105.58	7.15	4.78	4.74	1.41	47.78	30.50	---
Gypsum	00-15	113.33	7.27	6.67	12.80	2.62	65.16	24.80	---
	15-30	102.00	7.22	5.03	5.21	1.54	50.74	31.27	---
	30-45	131.92	7.73	3.74	2.66	1.41	37.04	29.31	---
	45-60	120.25	7.62	4.42	4.37	1.21	44.11	26.79	---
Soil Embankment	00-15	117.58	7.89	2.83	1.53	0.49	27.16	28.60	---
	15-30	96.17	7.29	3.90	2.51	0.76	38.44	30.20	---
	30-45	126.25	7.59	3.39	2.04	0.64	32.75	28.28	---
	45-60	121.50	7.17	4.59	4.77	1.21	45.49	28.85	---

Table 12. Means of analyses performed on nonirrigated samples: 1981.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Control	00-15	116.92	7.78	3.21	1.73	0.63	32.37	30.11	2.28
	15-30	109.83	7.87	3.86	2.71	0.83	40.44	31.54	0.96
	30-45	128.00	7.83	3.30	2.82	0.72	33.42	28.02	1.59
	45-60	125.08	7.97	3.17	1.84	0.54	32.38	30.62	1.20
Calcium Chloride	00-15	82.17	7.15	7.08	9.63	2.09	68.94	29.87	29.37
	15-30	108.08	7.45	5.78	3.91	1.23	58.55	38.67	30.80
	30-45	106.58	7.12	6.82	7.07	1.67	71.37	40.39	23.78
	45-60	98.08	7.48	5.47	3.44	1.21	55.47	37.81	18.08
Topsoil	00-15	71.17	7.67	3.10	3.44	0.99	31.83	21.38	1.01
	15-30	114.00	7.72	4.10	2.78	0.82	44.27	32.99	0.97
	30-45	114.58	7.57	4.72	4.22	1.25	50.68	31.42	0.81
	45-60	109.00	7.59	4.01	3.31	1.00	42.57	28.83	0.67
Manure	00-15	114.33	7.70	3.08	2.05	1.05	30.75	25.74	2.75
	15-30	102.33	6.85	5.73	5.41	1.85	62.13	34.95	1.13
	30-45	111.42	6.73	5.31	5.35	1.77	57.96	32.45	4.48
	45-60	109.17	7.17	4.40	3.26	1.29	45.65	31.52	2.16
Sewage Sludge	00-15	111.92	7.64	3.50	1.57	0.62	34.71	33.93	0.48
	15-30	113.42	7.59	4.06	1.92	0.71	41.94	36.71	0.47
	30-45	118.25	7.35	3.90	2.59	0.87	40.56	31.10	0.66
	45-60	111.92	7.17	4.32	2.50	0.89	44.13	33.59	0.53
Gypsum	00-15	119.25	7.37	6.50	11.02	2.69	68.68	28.59	0.38
	15-30	104.50	7.55	5.27	4.34	1.48	57.36	35.64	0.56

(CONTINUED)

Table 12. Concluded.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Gypsum	30-45	116.80	7.47	4.78	3.54	1.17	51.30	34.34	0.40
	45-60	116.90	7.60	4.84	3.52	1.26	51.45	35.35	4.67
Soil Embankment	00-15	117.60	7.62	2.79	1.38	0.74	28.47	27.80	0.59
	15-30	114.50	7.28	4.20	2.45	0.99	44.23	34.29	0.36
	30-45	117.20	7.41	3.71	2.35	0.97	39.42	30.90	0.47
	45-60	119.90	7.44	3.80	3.62	1.53	39.66	27.68	0.63

Table 13. Means of analyses performed on nonirrigated samples: 1984.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Control	00-15	132.75	7.51	2.92	1.71	0.45	28.77	27.60	0.55
	15-30	124.58	7.43	3.59	2.43	0.51	36.26	29.96	0.72
	30-45	138.00	7.60	3.71	2.33	0.52	38.06	32.49	0.70
	45-60	139.08	7.52	3.85	2.42	0.60	39.78	33.54	0.53
Calcium Chloride	00-15	88.00	6.84	7.90	13.70	2.69	71.38	26.70	40.64
	15-30	106.17	6.83	7.66	8.85	2.27	74.42	35.32	28.21
	30-45	112.58	6.76	7.90	6.57	1.93	80.67	43.63	26.05
	45-60	138.58	7.07	5.52	3.72	0.88	56.96	38.76	15.25
Topsoil	00-15	72.00	7.22	2.90	3.55	0.70	28.28	19.97	1.02
	15-30	115.83	7.35	4.49	3.04	0.83	45.60	34.26	0.75
	30-45	132.50	7.28	5.38	4.50	1.06	56.13	34.73	0.55
	45-60	156.83	7.36	3.78	2.35	0.69	38.70	31.93	0.35
Manure	00-15	119.42	7.09	3.49	2.47	0.61	35.27	28.20	2.31
	15-30	105.75	6.90	6.33	5.91	1.51	66.54	37.31	0.78
	30-45	109.83	6.66	6.40	5.88	1.51	67.17	34.41	0.55
	45-60	137.33	6.89	4.33	3.42	0.81	45.09	30.51	0.58
Sewage Sludge	00-15	123.42	7.21	3.31	1.56	0.56	33.10	32.16	0.59
	15-30	127.08	7.21	4.20	3.67	0.83	42.81	31.33	0.86
	30-45	119.00	7.01	4.41	2.90	0.76	45.70	34.72	0.94
	45-60	122.83	6.99	4.12	2.22	0.53	42.54	35.91	0.48
Gypsum	00-15	118.25	7.04	7.63	15.52	3.17	76.25	26.38	0.58
	15-30	113.83	7.26	5.32	4.37	1.14	55.28	36.24	0.59

(CONTINUED)

Table 13. Concluded.

Treatment	Depth	Sat.	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Gypsum	30-45	133.75	7.38	3.93	2.27	0.56	40.45	33.93	0.53
	45-60	144.17	7.47	3.88	2.45	0.72	39.74	32.03	0.44
Soil Embankment	00-15	134.17	7.56	2.69	1.32	0.37	26.72	28.98	0.51
	15-30	109.67	7.25	4.23	2.85	0.75	43.94	32.98	0.62
	30-45	122.17	7.22	5.13	3.74	1.06	53.76	35.23	0.49
	45-60	131.75	7.30	4.94	3.71	1.12	51.44	32.85	0.43

Table 14. Means of analyses performed on irrigated samples: 1978.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Control	00-15	110.00	7.84	3.03	2.17	1.18	28.76	24.66	--
	15-30	106.25	7.75	3.43	2.02	0.66	33.71	29.42	--
	30-45	109.00	7.82	3.68	2.21	0.72	39.81	31.05	--
	45-60	113.17	7.82	3.32	1.80	0.66	32.65	30.27	--
Calcium Chloride	00-15	85.08	7.36	5.02	11.81	1.91	42.07	16.82	--
	15-30	101.33	7.63	4.82	2.93	1.00	44.97	32.41	--
	30-45	103.33	7.65	5.40	3.57	1.13	56.14	36.76	--
	45-60	109.33	7.70	4.95	3.09	1.01	46.82	35.06	--
Topsoil	00-15	59.08	7.47	3.24	6.74	1.91	30.57	15.88	--
	15-30	95.58	7.61	3.51	2.84	0.80	34.42	25.91	--
	30-45	95.50	7.78	3.14	2.05	0.58	30.42	27.17	--
	45-60	113.75	7.80	2.97	1.85	0.47	29.12	27.29	--
Manure	00-15	107.92	7.62	3.57	3.10	1.05	34.09	24.25	--
	15-30	97.75	7.42	4.20	3.64	1.10	41.57	28.07	--
	30-45	99.00	7.76	3.77	3.50	1.12	37.53	28.13	--
	45-60	99.50	7.43	4.50	4.50	1.22	44.60	27.98	--
Sewage Sludge	00-15	103.83	7.47	4.06	3.90	1.27	39.46	25.30	--
	15-30	100.50	7.89	3.95	2.51	0.73	38.75	30.84	--
	30-45	103.33	7.70	3.65	2.00	0.77	33.54	30.97	--
	45-60	100.92	7.61	4.21	2.96	0.88	42.25	30.99	--
Gypsum	00-15	106.00	7.42	5.71	9.69	2.11	54.68	25.16	--
	15-30	100.50	7.60	4.14	2.62	0.65	43.19	34.40	--

(CONTINUED)

Table 14. Concluded.

Treatment	Depth (cm)	Sat.	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Gypsum	30-45	104.83	7.51	4.13	2.64	0.73	42.42	33.74	--
	45-60	97.92	7.36	4.60	3.21	0.93	47.10	35.65	--
Soil Embankment	00-15	119.25	7.77	3.47	1.90	0.62	33.77	30.10	--
	15-30	95.67	7.75	4.27	3.40	0.91	43.22	30.17	--
	30-45	101.83	7.76	3.36	1.52	0.53	32.74	33.02	--
	45-60	113.08	8.02	3.08	1.41	0.41	30.11	32.92	--

Table 15. Means of analyses performed on irrigated samples: 1981.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Control	00-15	118.42	7.52	3.37	1.97	0.67	32.52	29.45	0.42
	15-30	114.42	7.72	3.46	1.76	0.62	33.88	31.58	0.33
	30-45	127.17	7.84	3.22	1.39	0.52	31.62	33.14	0.35
	45-60	132.50	7.86	2.96	1.17	0.42	29.12	32.75	0.36
Calcium Chloride	00-15	104.83	7.38	4.25	6.24	1.21	38.87	22.14	8.90
	15-30	105.75	7.59	5.01	2.48	0.75	47.83	38.31	17.72
	30-45	116.33	7.70	4.58	1.85	0.62	43.92	40.71	13.33
	45-60	118.58	7.78	4.02	1.77	0.56	39.08	43.02	10.99
Topsoil	00-15	90.67	7.45	4.30	4.81	1.57	41.73	23.30	0.87
	15-30	108.75	7.77	3.59	2.16	0.72	35.15	29.95	0.56
	30-45	121.17	7.91	3.37	1.68	0.57	33.19	32.23	0.71
	45-60	121.92	7.93	3.18	1.45	0.51	31.48	33.54	0.52
Manure	00-15	132.00	7.31	4.40	3.06	1.15	43.07	30.89	0.91
	15-30	127.83	7.57	4.01	2.16	0.75	40.05	33.33	0.69
	30-45	125.92	7.44	4.01	2.02	0.68	40.29	35.45	0.46
	45-60	125.08	7.65	3.82	1.63	0.57	37.52	36.18	1.17
Sewage Sludge	00-15	112.00	7.57	4.12	3.12	1.08	43.06	31.98	0.75
	15-30	113.92	7.84	3.34	1.47	0.47	32.64	33.95	0.49
	30-45	115.25	7.82	3.29	1.47	0.50	32.06	32.20	0.50
	45-60	117.42	7.74	3.28	1.49	0.47	31.90	32.28	0.41
Gypsum	00-15	128.33	7.54	4.74	2.84	0.88	47.44	35.16	0.31
	15-30	124.50	7.58	3.93	1.87	0.65	39.42	35.05	0.28

(CONTINUED)

Table 15. Concluded.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Gypsum	30-45	120.25	7.64	3.78	1.80	0.65	37.43	33.80	0.32
	45-60	127.25	7.73	3.60	1.59	0.61	35.39	31.63	0.36
Soil Embankment	00-15	128.83	7.73	3.69	1.70	0.62	34.81	32.94	0.59
	15-30	115.00	7.80	3.82	1.64	0.61	36.97	35.71	0.54
	30-45	127.83	7.95	3.32	1.25	0.42	32.28	35.78	0.49
	45-60	126.83	7.71	4.24	2.08	0.72	42.33	37.67	0.35

Table 16. Means of analyses performed on irrigated samples: 1984.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Control	00-15	135.83	7.34	3.87	2.29	0.74	38.30	31.71	0.57
	15-30	120.67	7.47	4.20	2.58	0.75	42.85	33.81	0.41
	30-45	121.33	7.46	4.65	2.64	0.71	47.51	37.43	0.40
	45-60	131.67	7.38	4.40	2.36	0.68	44.57	36.74	0.41
Calcium Chloride	00-15	94.17	7.04	4.63	9.37	2.07	39.99	17.27	10.90
	15-30	109.58	7.24	6.92	5.90	1.97	66.58	32.34	24.17
	30-45	127.92	7.43	6.55	3.40	1.17	65.14	45.22	25.95
	45-60	121.25	7.55	5.98	2.40	0.91	59.75	47.53	21.28
Topsoil	00-15	74.42	7.31	4.03	6.25	1.84	39.16	18.99	0.81
	15-30	114.17	7.55	5.90	6.09	2.02	59.72	32.74	0.62
	30-45	132.75	7.70	4.02	2.28	0.68	41.02	34.22	0.42
	45-60	141.25	7.75	3.46	1.71	0.45	34.82	34.17	0.40
Manure	00-15	114.75	7.30	5.32	6.01	1.75	52.58	29.43	1.19
	15-30	105.58	7.23	5.91	5.37	1.62	60.88	34.06	0.94
	30-45	121.67	7.34	4.60	2.88	0.78	46.72	34.92	0.47
	45-60	112.08	7.36	4.68	3.02	0.85	44.87	34.71	0.41
Sewage Sludge	00-15	137.33	7.41	4.96	4.30	1.51	49.01	29.21	0.80
	15-30	115.92	7.52	4.46	2.90	0.93	45.01	33.72	0.43
	30-45	114.75	7.43	4.28	2.53	0.76	43.71	34.33	0.38
	45-60	108.00	7.37	4.32	2.73	0.84	43.82	32.81	0.39
Gypsum	00-15	121.33	7.09	8.52	14.29	4.32	83.16	24.93	0.56
	15-30	107.42	7.25	5.86	4.62	1.39	61.03	36.43	0.35

(CONTINUED)

Table 16. Concluded.

Treatment	Depth (cm)	Sat. (%)	pH	EC (dS/m)	Ca (me/L)	Mg (me/L)	Na (me/L)	SAR	Cl (me/L)
Gypsum	30-45	119.83	7.28	4.80	3.56	1.08	49.08	35.56	0.32
	45-60	125.42	7.43	3.90	2.25	0.60	39.56	33.96	0.41
Soil Embankment	00-15	132.75	7.31	4.09	2.55	0.89	40.57	31.24	0.97
	15-30	113.83	7.26	4.24	2.67	0.85	42.37	33.01	0.39
	30-45	126.00	7.35	4.15	2.40	0.65	42.17	34.56	0.44
	45-60	136.67	7.42	4.43	2.56	0.78	46.21	37.58	0.32

Table 17. Mean yields for nonirrigated plots.

TREATMENT	YEAR		
	1980	1981	1983
	(g/0.25 sq. m.)	(g/0.25 sq. m.)	(g/0.25 sq. m.)
Control	1.78	11.70	0.00
Calcium Chloride	8.08	35.10	13.87
Topsoil	11.70	74.12	41.87
Manure	4.47	26.02	2.32
Sewage Sludge	3.33	28.47	6.77
Gypsum	4.67	19.97	6.93
Soil Embankment	1.27	6.77	0.00

Table 18. Mean yields for irrigated plots.

TREATMENT	YEAR		
	1980	1981	1983
	(g/0.25 sq. m.)	(g/0.25 sq. m.)	(g/0.25 sq. m.)
Control	11.38	18.95	0.00
Calcium Chloride	42.00	83.42	17.85
Topsoil	41.95	95.78	23.27
Manure	13.87	20.23	0.00
Sewage Sludge	17.70	28.68	2.22
Gypsum	14.63	23.88	0.00
Soil Embankment	0.00	8.80	0.00

Table 19. Effect of treatment and the year x treatment interaction on sat.% at the 0 to 15 cm depth.

Treatment	Sat.%			
	Irrigated			Non-Irrigated
	1978	1981	1984	
Topsoil	59a	91a	74a	66a
$CaCl_2$	85ab	105ab	94ab	81a
Manure	108 bc	132 b	115 bc	114 b
Gypsum	106 bc	128 b	121 bc	117 b
Sewage Sludge	104 bc	112ab	137 c	115 b
Control	110 bc	118ab	136 c	121 b
Soil Embankment	119 c	129 b	133 c	123 b

Means with different subscripts (a,b,c) are significantly different at $p<0.05$.

Table 20. Effect of treatment and the year x treatment interaction on pH at the 0 to 15 cm depth.

Treatment	pH			
	Irrigated			Non-Irrigated
	1978	1981	1984	
$CaCl_2$	7.36a	7.38ab	7.04a	7.04a
Gypsum	7.42ab	7.54ab	7.09a	7.22ab
Topsoil	7.47abc	7.45ab	7.31a	7.46ab
Sewage Sludge	7.47abc	7.57ab	7.41a	7.52 b
Manure	7.62abc	7.31a	7.30a	7.56 b
Control	7.84 c	7.52ab	7.34a	7.69 b
Soil Embankment	7.77 bc	7.73 c	7.31a	7.70 b

Means with different subscripts (a,b,c) are significantly different at $p<0.05$.

Table 21. Effect of treatment and the year x treatment interaction on EC.

Treatment	EC ($dS\ m^{-1}$)			
	Irrigated (0-15 cm)			Non-Irrigated (15-30 cm)
	1978	1981	1984	
$CaCl_2$	5.02ab	4.25a	4.63 b	6.82a
Gypsum	5.71a	4.74a	8.52a	5.21abc
Topsoil	3.24 b	4.30a	4.03 b	4.27 bc
Sewage Sludge	4.06ab	4.12a	4.95 b	3.89 bc
Manure	3.57ab	4.40a	5.32 b	5.72ab
Control	3.03 b	3.37a	3.87 b	3.72 c
Soil Embankment	3.47ab	3.69a	4.09 b	4.11 bc

Means with different subscripts (a,b,c) are significantly different at $p<0.05$.

Table 22. Effect of treatment and the year x treatment interaction on concentrations of Ca at the 0 to 15 cm depth.

Treatment	Ca (me L^{-1})			
	Irrigated			Non-Irrigated
	1978	1981	1984	
$CaCl_2$	11.81a	6.24a	9.37ab	13.06a
Gypsum	9.69ab	2.84a	14.29a	13.12a
Topsoil	6.74abc	4.81a	6.25 bc	4.24ab
Manure	3.10 bc	3.06a	6.01 bc	2.26 b
Sewage Sludge	3.90 bc	3.12a	4.30 bc	1.75 b
Control	2.17 c	1.97a	2.29 c	1.53 b
Soil Embankment	1.90 c	1.70a	2.55 c	1.41 b

Means with different subscripts (a,b,c) are significantly different at $p<0.05$.

Table 23. Effect of treatment and the year x treatment interaction on concentrations of Mg at the 0 to 15 cm depth.

Treatment	Mg (me L^{-1})			
	Irrigated			Non-Irrigated
	1978	1981	1984	
$CaCl_2$	1.91ab	1.21a	2.07 b	2.37ab
Gypsum	2.11a	0.88a	4.32a	2.82a
Topsoil	1.90ab	1.57a	1.84 b	1.06ab
Manure	1.05ab	1.15a	1.75 b	0.79ab
Sewage Sludge	1.27ab	1.08a	1.51 b	0.62 b
Control	1.18ab	0.67a	0.74 b	0.49 b
Soil Embankment	0.62 b	0.62a	0.89 b	0.52 b

Means with different subscripts (a,b) are significantly different at $p<0.05$.

Table 24. Effect of treatment and the year x treatment interaction on concentrations of Na.

Treatment	Na (me L^{-1})			
	Irrigated (0 to 15 cm)			Non-Irrigated (15 to 30 cm)
	1978	1981	1984	
$CaCl_2$	42.07ab	38.87a	39.99 b	66.29a
Gypsum	54.68a	47.44a	83.16a	54.46abc
Topsoil	30.57 b	41.73a	39.16 b	43.69 bc
Manure	34.09ab	43.07a	52.58 b	59.81ab
Sewage Sludge	39.46ab	43.06a	49.01 b	39.57 c
Control	28.76 b	32.52a	38.30 b	37.69 c
Soil Embankment	33.77ab	34.81a	40.57 b	42.08 bc

Means with different subscripts (a,b,c) are significantly different at $p<0.05$.

Table 25. Effect of treatment and the year x treatment interaction on SAR at the 0 to 15 cm depth.

Treatment	SAR					
	Irrigated			Non-Irrigated		
	1978	1981	1984	1978	1981	1984
$CaCl_2$	17b	22c	17d	21ab	30ab	27ab
Gypsum	25a	35a	25bc	25ab	29ab	26ab
Topsoil	16b	23bc	19cd	16b	21b	20b
Manure	24a	31a	29ab	27a	26ab	28ab
Sewage Sludge	25a	32a	29ab	29a	34a	32a
Control	25a	30ab	32a	31a	30ab	28ab
Soil Embankment	30a	33a	31ab	29a	29ab	29ab

Means with different subscripts (a,b,c,d) are significantly different at $p<0.05$.

Table 26. Effect of treatment and the year x treatment interaction on concentrations of Cl.

Treatment	log Cl (me L)$^{-1}$										
	Irrigated (cm)						Non-Irrigated (cm)				
	0-15	15-30	30-45		45-60		0-15		15-30	30-45	45-60
			1981	1984	1981	1984	1981	1984			
$CaCl_2$	0.92a	1.29a	1.12a	1.40a	1.01a	1.32a	1.20a	1.47a	1.39a	1.34a	1.18a
Manure	-0.00b	-0.12b	-0.41b	-0.33b	-0.23b	-0.39b	0.13b	0.19b	-0.13b	-0.23b	-0.17b
Topsoil	-0.16b	-0.28bc	-0.29b	-0.40b	-0.39b	-0.41b	-0.13b	-0.05b	-0.14b	-0.25b	-0.34b
Embankment	-0.23b	-0.40bc	-0.40b	-0.37b	-0.48b	-0.50b	-0.26b	-0.31b	-0.35b	-0.36b	-0.37b
Sewage Sludge	-0.20b	-0.42bc	-0.44b	-0.43b	-0.49b	-0.44b	-0.34b	-0.24b	-0.29b	-0.27b	-0.37b
Control	-0.33b	-0.45bc	-0.49b	-0.40b	-0.45b	-0.41b	0.08b	-0.27b	-0.16b	-0.10b	-0.18b
Gypsum	-0.38b	-0.51c	-0.52b	-0.50b	-0.46b	-0.40b	-0.44b	-0.29b	-0.30b	-0.38b	-0.28b

Means with different subscripts (a,b,c,d) are significantly different at $p<0.05$.

Table 27. Interaction of treatment with year for sat.%, pH, EC, Ca, Mg, Na, SAR and Cl.

Soil Variable	Irrigation Mode	Depth (cm)	Year	Treatment: Control	$CaCl_2$	Topsoil	Manure	Sewage	Gypsum	Embankment
Sat.%	Irrigated	0-15	1978	110 a	85 a	59 a	108 a	104 a	106 a	119 a
			1981	118 ab	105 a	91 b	132 a	112 ab	121 a	129 a
			1984	136 b	94 a	74 ab	115 a	137 b	128 a	133 a
pH	Irrigated	0-15	1978	7.84a	7.36a	7.47a	7.63a	7.47a	7.42ab	7.77a
			1981	7.53ab	7.38a	7.45a	7.31a	7.58a	7.54a	7.73a
			1984	7.37b	7.04a	7.31a	7.30a	7.41a	7.10b	7.32b
EC ($dS\ m^{-1}$)	Irrigated	0-15	1978	3.03a	5.02a	3.24a	3.57a	4.06a	5.71a	3.47a
			1981	3.38a	4.25a	4.30a	4.40a	4.13a	4.74a	3.69a
			1984	3.87a	4.63a	4.03a	5.32a	4.96a	8.53b	4.10a
		45-60	1978	3.32a	4.95ab	4.50a	4.50a	4.21a	4.60a	3.08a
			1981	2.96a	4.02a	3.83a	3.83a	3.28a	3.60a	4.24a
			1984	4.40a	5.99b	4.68a	4.68a	4.32a	3.90a	4.43a
Ca ($me\ L^{-1}$)	Irrigated	0-15	1978	2.17a	11.81a	6.74a	3.10a	3.90a	9.69a	1.90a
			1981	1.98a	6.24a	4.81a	3.06a	3.12a	2.84b	1.70a
			1984	2.29a	9.37a	6.25a	6.01a	4.30a	14.29a	2.55a
Mg ($me\ L^{-1}$)	Irrigated	0-15	1978	1.18a	1.91a	1.91a	1.05a	1.28a	2.11a	0.62a
			1981	0.68a	1.21a	1.58a	1.15a	1.08a	0.88a	0.63a
			1984	0.74a	2.07a	1.84a	1.75a	1.51a	4.32b	0.89a

Continued . . .

Table 27. Concluded.

Soil Variable	Irrigation Mode	Depth (cm)	Year	Treatment						
				Control	$CaCl_2$	Topsoil	Manure	Sewage	Gypsum	Embankment
Na (me L^{-1})	Irrigated	0-15	1978	28.76a	42.07a	30.57a	34.09a	39.01a	54.68a	40.58a
			1981	32.53a	39.99a	41.73a	43.07a	43.06a	47.44a	34.80a
			1984	38.30a	38.88a	39.16a	52.58a	39.46a	83.16b	33.77a
		45-60	1978	32.65a	46.82ab	29.13a	44.60a	42.25a	47.10a	30.11a
			1981	29.12a	39.08a	31.48a	37.52a	31.90a	35.39a	42.33a
			1984	44.58a	59.75b	34.82a	44.87a	43.82a	39.56a	46.21a
SAR	Irrigated	0-15	1978	25a	17a	16a	24a	25a	25a	30a
			1981	30ab	22a	23b	31b	32b	35b	33a
			1984	32b	17a	19ab	29ab	29ab	25a	31a
		15-30	1978	29a	32a	26a	28a	31a	34a	30a
			1981	32a	38a	30a	33a	34a	35a	36a
			1984	34a	32a	33a	34a	34a	36a	33a
	Non-Irrigated	0-15	1978	31a	21a	16a	27a	29a	25a	29a
			1981	30a	30b	21a	26a	34a	29a	28a
			1984	28a	27ab	20a	28a	32a	26a	29a
log Cl (me L^{-1})	Irrigated	30-45	1981	-0.49a	1.12a	-0.29a	-0.41a	-0.44a	-0.52a	-0.40
			1984	-0.40a	1.40b	-0.40a	-0.33a	-0.43a	-0.50a	-0.37
		45-60	1981	-0.45a	1.01a	-0.39a	-0.23a	-0.49a	-0.46a	-0.48
			1984	-0.41a	1.32b	-0.41a	-0.39a	-0.44a	-0.40a	-0.50
	Non-Irrigated	0-15	1981	0.08a	1.20a	-0.13a	0.13a	-0.34a	-0.44a	-0.26
			1984	-0.27b	1.47b	-0.05a	0.19a	-0.24a	-0.29a	-0.31

Means with different subscripts (a,b,c,d) are significantly different at $p<0.05$.

Table 28. Test for trends for depth at the non-irrigated plots in 1978.

Treatment	Depth (cm)	Sat.%	pH	EC (dS m^{-1})	Ca	Mg (me L^{-1})	Na	SAR
Control	0-15	NS	NS	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS	NS	NS
	30-45	NS	NS	NS	NS	NS	NS	NS
	45-60	NS	NS	NS	NS	NS	NS	NS
$CaCl_2$	0-15	74	NS	6.73	15.85	NS	NS	21
	15-30	101	NS	7.01	7.99	NS	NS	34
	30-45	118	NS	5.34	4.80	NS	NS	37
	45-60	106	NS	5.52	4.28	NS	NS	36
L		55			100			74
Q		43						23
Topsoil	0-15	56	NS	NS	NS	NS	NS	116
	15-30	90	NS	NS	NS	NS	NS	29
	30-45	113	NS	NS	NS	NS	NS	28
	45-60	107	NS	NS	NS	NS	NS	27
L		79						47
Q		19						47
Manure	0-15	NS	7.90	2.98	NS	NS	28.67	NS
	15-30	NS	7.12	5.11	NS	NS	50.76	NS
	30-45	NS	7.03	4.71	NS	NS	45.91	NS
	45-60	NS	7.35	4.22	NS	NS	40.65	NS
L			27					31
Q			64	100			100	68

Continued . . .

Table 28. Concluded.

Treatment	Depth (cm)	Sat.%	pH	EC (dS m^{-1})	Ca	Mg (me L^{-1})	Na	SAR
Sewage Sludge	0-15	NS	NS	NS	NS	NS	33.53	NS
	15-30	NS	NS	NS	NS	NS	33.95	NS
	30-45	NS	NS	NS	NS	NS	35.58	NS
	45-60	NS	NS	NS	NS	NS	47.78	NS
L							100	
Gypsum	0-15	113	NS	6.67	12.80	2.62	65.16	NS
	15-30	102	NS	5.03	5.21	1.54	50.74	NS
	30-45	132	NS	3.74	2.66	1.41	37.04	NS
	45-60	120	NS	4.42	4.37	1.21	44.11	NS
L		48		69	61	74	70	62
Q				30	39	25	27	38
C		52						
Soil Embankment	0-15	NS	NS	2.83	NS	NS	27.16	NS
	15-30	NS	NS	3.90	NS	NS	38.44	NS
	30-45	NS	NS	3.39	NS	NS	32.75	NS
	45-60	NS	NS	4.59	NS	NS	45.49	NS
L				100			100	

L Linear trend significant at $p<0.05$
Q Quadratic trend significant at $p<0.05$
C Cubic trend significant at $p<0.05$
L,Q,C Proportion of variance due to depth accounted for by the respective trends.
NS Not Significant.

Table 29. Test for trends for depth at the non-irrigated plots in 1981.

Treatment	Depth (cm)	Sat.%	Ca (me L^{-1})	SAR
Control	0-15	NS	NS	NS
	15-30	NS	NS	NS
	30-45	NS	NS	NS
	45-60	NS	NS	NS
$CaCl_2$	0-15	82	9.63	30
	15-30	108	3.91	31
	30-45	107	7.08	40
	45-60	98	3.44	38
L			100	56
Q		100		44
Topsoil	0-15	71	NS	21
	15-30	114	NS	33
	30-45	115	NS	31
	45-60	109	NS	29
L		62		24
Q		32		69
Manure	0-15	NS	NS	26
	15-30	NS	NS	35
	30-45	NS	NS	33
	45-60	NS	NS	32
Q				100
Sewage sludge	0-15	NS	NS	NS
	15-30	NS	NS	NS
	30-45	NS	NS	NS
	45-60	NS	NS	NS
Gypsum	0-15	NS	11.03	NS
	15-30	NS	4.34	NS
	30-45	NS	3.54	NS
	45-60	NS	3.52	NS
L			65	
Q			26	
Soil Embankment	0-15	NS	NS	28
	15-30	NS	NS	34
	30-45	NS	NS	31
	45-60	NS	NS	28

L Linear trend significant at $p<0.05$.
Q Quadratic trend significant at $p<0.05$.
L,Q Proportion of variance due to depth accounted for by the respective trends.
NS Not Significant.

Table 30. Test for trends for depth at the non-irrigated plots in 1984.

Treatment	Depth (cm)	Sat.%	EC (dS m^{-1})	Ca	Mg	Na	SAR	Cl (me L^{-1})
				(me L^{-1})				
Control	0-15	NS	NS	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS	NS	NS
	30-45	NS	NS	NS	NS	NS	NS	NS
	45-60	NS	NS	NS	NS	NS	NS	NS
$CaCl_2$	0-15	88	NS	13.70	2.69	NS	27	40.64
	15-30	106	NS	8.84	2.28	NS	35	28.21
	30-45	113	NS	6.58	1.93	NS	44	26.05
	45-60	139	NS	3.72	0.88	NS	39	15.25
L		100		100	100		63	100
Q							34	
Topsoil	0-15	72	2.90	NS	NS	28.28	20	NS
	15-30	116	4.49	NS	NS	45.60	34	NS
	30-45	133	5.38	NS	NS	56.13	35	NS
	45-60	157	3.78	NS	NS	38.70	32	NS
L		100					47	
Q			100			100	50	
Manure	0-15	NS	3.49	NS	NS	35.28	28	NS
	15-30	NS	6.33	NS	NS	66.54	37	NS
	30-45	NS	6.40	NS	NS	67.17	34	NS
	45-60	NS	4.33	NS	NS	45.09	31	NS
L								
Q			100			100	100	
Sewage Sludge	0-15	NS	NS	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS	NS	NS
	30-45	NS	NS	NS	NS	NS	NS	NS
	45-60	NS	NS	NS	NS	NS	NS	NS
L								
Q								
Gypsum	0-15	NS	7.63	15.53	3.16	76.25	26	NS
	15-30	NS	5.32	4.37	1.14	55.28	36	NS
	30-45	NS	3.93	2.28	0.56	40.45	34	NS
	45-60	NS	3.88	2.45	0.72	39.74	32	NS
L			100	71	71	100		
Q				27	27		100	
Soil Embankment	0-15	NS	2.69	NS	NS	26.72	NS	NS
	15-30	NS	4.23	NS	NS	43.94	NS	NS
	30-45	NS	5.13	NS	NS	53.76	NS	NS
	45-60	NS	4.94	NS	NS	51.44	NS	NS

L Linear trend significant at $p<0.05$.
Q Quadratic trend significant at $p<0.05$.
L,Q Proportion of variance due to depth accounted for by the respective trends.
NS Not Significant.

Table 31. Test for trends for depth at the irrigated plots in 1978.

Treatment	Depth (cm)	Sat.%	Ca	Mg	Na	SAR
			------- (me L^{-1}) ---------			
Control	0-15	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS
	30-45	NS	NS	NS	NS	NS
	45-60	NS	NS	NS	NS	NS
$CaCl_2$	0-15	85	11.81	1.91	42.07	17
	15-30	101	2.93	1.01	44.97	32
	30-45	103	3.57	1.14	56.14	37
	45-60	109	3.09	1.01	46.82	35
			57	100	100	70
			33			30
			9			
Topsoil	0-15	59	6.74	1.91	NS	16
	15-30	96	2.84	0.80	NS	26
	30-45	96	2.05	0.58	NS	27
	45-60	114	1.85	0.48	NS	27
		84	75	77		71
		9	23	20		23
		9				9
Manure	0-15	NS	NS	NS	NS	24
	15-30	NS	NS	NS	NS	28
	30-45	NS	NS	NS	NS	28
	45-60	NS	NS	NS	NS	28
Q						100
Sewage Sludge	0-15	NS	NS	NS	NS	25
	15-30	NS	NS	NS	NS	31
	30-45	NS	NS	NS	NS	31
	45-60	NS	NS	NS	NS	31
L						57
Q						33
Gypsum	0-15	NS	9.69	2.11	54.68	25
	15-30	NS	2.62	0.65	43.19	34
	30-45	NS	2.64	0.73	42.42	34
	45-60	NS	3.21	0.93	47.10	36
L			53	45		66
Q			39	47		21
C			8			13
Soil Embankment	0-15	119	NS	NS	NS	NS
	15-30	96	NS	NS	NS	NS
	30-45	102	NS	NS	NS	NS
	45-60	113	NS	NS	NS	NS
Q		100				

L Linear trend significant at $p<0.05$.
Q Quadratic trend significant at $p<0.05$.
C Cubic trend significant at $p<0.05$.
L,Q,C Proportion of variance accounted for by the respective trends.
NS Not Significant

Table 32. Test for trends for depth at the irrigated plots in 1981.

Treatment	Depth (cm)	Sat.%	EC (dS m^{-1})	Ca -- (me L^{-1}) --	Mg	SAR	Cl (me L^{-1})
Control	0-15	118	NS	NS	NS	NS	NS
	15-30	114	NS	NS	NS	NS	NS
	30-45	127	NS	NS	NS	NS	NS
	45-60	133	NS	NS	NS	NS	NS
L		100					
$CaCl_2$	0-15	NS	NS	6.24	1.21	22	8.90
	15-30	NS	NS	2.48	0.75	38	17.72
	30-45	NS	NS	1.85	0.62	41	13.33
	45-60	NS	NS	1.77	0.56	43	10.99
L				69	78	81	76
Q				29	21	17	21
Topsoil	0-15	91	4.30	4.81	1.58	23	NS
	15-30	109	3.59	2.16	0.73	30	NS
	30-45	121	3.38	1.68	0.57	32	NS
	45-60	122	3.18	1.45	0.51	33	NS
L		100	100	73	73	100	
Q				22	23		
Manure	0-15	NS	NS	3.06	1.15	NS	NS
	15-30	NS	NS	2.16	0.75	NS	NS
	30-45	NS	NS	2.03	0.68	NS	NS
	45-60	NS	NS	1.63	0.58	NS	NS
L				100	79		
Q					17		
Sewage Sludge	0-15	NS	4.13	3.12	1.08	NS	NS
	15-30	NS	3.34	1.47	0.47	NS	NS
	30-45	NS	3.29	1.48	0.50	NS	NS
	45-60	NS	3.28	1.49	0.47	NS	NS
L			100	100	63		
Q					29		
Gypsum	0-15	NS	4.74	NS	NS	NS	NS
	15-30	NS	3.93	NS	NS	NS	NS
	30-45	NS	3.78	NS	NS	NS	NS
	45-60	NS	3.60	NS	NS	NS	NS
L			100				
Soil Embankment	0-15	NS	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS	NS
	30-45	NS	NS	NS	NS	NS	NS
	45-60	NS	NS	NS	NS	NS	NS

L Linear trend significant at $p<0.05$.
Q Quadratic trend significant at $p<0.05$.
C Cubic trend significant at $p<0.05$.
L,Q,C Proportion of variance due to depth accounted for by the respective trends.
NS Not Significant.

Table 33. Test for trends for depth at the irrigated plots in 1984.

Treatment	Depth (cm)	Sat.%	EC (dS m^{-1})	Ca	Mg (me L^{-1})	Na	SAR	Cl (me L^{-1})
Control	0-15	NS	NS	NS	NS	NS	32	NS
	15-30	NS	NS	NS	NS	NS	34	NS
	30-45	NS	NS	NS	NS	NS	37	NS
	45-60	NS	NS	NS	NS	NS	37	NS
L							100	
$CaCl_2$	0-15	94	4.63	9.37	2.07	39.99	17	10.90
	15-30	110	6.92	5.90	1.97	66.58	32	24.18
	30-45	128	6.55	3.40	1.17	65.14	45	25.95
	45-60	121	5.98	2.40	0.91	59.75	48	21.28
L		100	34	100	100	45	92	48
Q			59			51	7	51
Topsoil	0-15	74	NS	6.25	1.84	39.16	19	NS
	15-30	114	NS	6.09	2.03	59.73	33	NS
	30-45	133	NS	2.28	0.68	41.03	34	NS
	45-60	141	NS	1.71	0.45	34.82	34	NS
L		89		100	100		62	
Q		11				100	33	
Manure	0-15	NS	NS	6.01	1.75	NS	29	NS
	15-30	NS	NS	5.37	1.62	NS	34	NS
	30-45	NS	NS	2.88	0.78	NS	35	NS
	45-60	NS	NS	3.03	0.85	NS	35	NS
L				100	100		100	
Q								
Sewage Sludge	0-15	137	NS	NS	NS	NS	29	NS
	15-30	116	NS	NS	NS	NS	34	NS
	30-45	115	NS	NS	NS	NS	34	NS
	45-60	108	NS	NS	NS	NS	33	NS
L		100						
Q							100	
Gypsum	0-15	NS	8.53	14.29	4.32	83.16	25	NS
	15-30	NS	5.86	4.62	1.39	61.03	36	NS
	30-45	NS	4.80	3.56	1.08	49.08	36	NS
	45-60	NS	3.90	2.25	0.60	39.56	34	NS
L			90	76	76	100	44	
Q			9	20	20		52	
C					4			
Soil Embankment	0-15	NS	NS	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS	NS	NS
	30-45	NS	NS	NS	NS	NS	NS	NS
	45-60	NS	NS	NS	NS	NS	NS	NS

L Linear trend significant at $p<0.05$
Q Quadratic trend significant at $p<0.05$
C Cubic trend significant at $p<0.05$
L,Q,C Proportion of variance due to depth accounted for by the respective trends.
NS Not Significant.

Table 34. Interaction of year x treatment for the yield data.

Year	Treatment	Yield (g 0.25 m^{2-1}) Non-Irrigated	Irrigated
1980	Topsoil	11.70 a	41.95 a
	$CaCl_2$	8.08 a	42.00 a
	Gypsum	4.67 a	14.63 b
	Manure	4.47 a	13.87 b
	Sewage Sludge	3.33 a	17.70 b
	Control	1.78 a	11.38 b
	Soil Embankment	1.27 a	0.00 c
1981	Topsoil	74.12 a	95.78 a
	$CaCl_2$	35.10 b	83.42 a
	Sewage Sludge	28.47 bc	28.68 b
	Manure	26.02 bc	20.23 bc
	Gypsum	19.97 bc	23.88 bc
	Control	11.70 bc	18.95 bc
	Soil Embankment	6.77 c	8.80 c
1983	Topsoil	41.87 a	23.27 a
	$CaCl_2$	13.87 b	17.85 ab
	Gypsum	6.93 b	0.00 b
	Sewage Sludge	6.77 b	2.22 b
	Manure	2.33 b	0.00 b
	Control	0.00 b	0.00 b
	Soil Embankment	0.00 b	0.00 b

a,b,c Means with different subscripts (a,b,c,) are significantly different at $p<0.05$.